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MODELS FOR LONG-RANGE AND MESOSCALE TRANSPORT AND DEPOSITION OF ATMOSPHERIC POLLUTANTS

PHASE I: MODELING SYSTEM DESIGN

EXECUTIVE SUMMARY

VOLUME I

August 1982

ARB-37-82-AQM

Prepared for

ONTARIO MINISTRY OF THE ENVIRONMENT
AIR RESOURCES BRANCH
880 Bay Street, 4th Floor
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Prepared by

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EXECUTIVE SUMMARY

1. INTRODUCTION

There is increasing evidence that the cumulative effect of a group of pollution sources can be noticed hundreds of kilometers from the sources. The most serious effect related to long-range transport may be the acidification of rain. Emissions of NO_x and SO_2 are oxidized as they are transported over long distances. These oxidized products, along with sulfur and nitrogen from natural sources, form acids when they combine with rain. The deposition of this "acid" rain in lakes has led to the reduction and even disappearance of fish species in lakes in Scandinavia, Canada, and the northeastern United States (see United States-Canada Memorandum of Intent on Transboundary Air Pollution 1981).

There is a clear need to investigate various pollutant emission control options as means to prevent further deterioration of the environment. In order to strike a balance between the costs of emission control and the benefits derived from the reduction in acid deposition, we must first understand the physical processes involved in the long-range and mesoscale transport of pollutants. This understanding can then be combined into the framework of long-range transport (LRT) and mesoscale models. Once these models have been validated against observations, they can be treated as reasonable analogues of the real world. They can be used to investigate cause-effect relationships by manipulating variables of the mathematical model. This type of experimentation in the real world would be impossible in the large complex system that influences and is influenced by the long-range transport of pollutants.

A LRT or mesoscale model is thus a mathematical description of the relevant physical system associated with the transport of pollutants. Physical relationships between the variables of the system are replaced by logical connections or equations in the mathematical model. A validated model can be used in the following ways:

- to incorporate existing knowledge in a well defined mathematical framework,

- to establish source-receptor relationships necessary for emission control,
- to interpolate between measurements,
- to establish the relative importance of variables in the system (this information can be used to plan large-scale field experiments), and
- to forecast events (given certain modifications to the model).

2. RATIONALE FOR TECHNICAL APPROACH

The physical system associated with the mesoscale and long-range transport of pollutants is extremely complex. The concentration of pollutants at large distances from a source is affected by prevailing meteorological conditions, diffusion, chemical transformation, and wet and dry scavenging. It is virtually impossible to conduct controlled experiments to determine the dominant elements of the system's behaviour. Apart from the fact that the quality of observed data is usually uncertain, the length of the available observational record is too short to even deduce empirical relationships between concentrations and emissions. This suggests that in spite of the limitations on our detailed scientific knowledge of long-range transport processes, it is necessary to rely on a complex model to make decisions on emission control.

Available LRT models are described in a paper by Eliassen (1980). For the most part, these models oversimplify the relevant physical processes. Wind field models generally neglect the significant vertical movement of air masses associated with certain meteorological conditions, and highly non-linear processes such as chemistry are parameterized in terms of linear rate constants. These simple models show a degree of skill in estimating long-term concentrations primarily because the values of these rate constants are often derived by calibrating model predictions against observations. This suggests that present models cannot be used to examine the effect of emission scenarios which are different from those corresponding to available concentration measurements.

Most models perform poorly in simulating short-term concentrations ($\sim$24-hour averages). Eliassen (1980) ascribes this deficiency to the neglect of mesoscale processes in LRT models. Furthermore, it is important to model non-linear processes such as in-cloud oxidation of SO_2 to $SO_4^=$ in order to estimate short-term concentrations.

Because the modeling system required by the Ontario Ministry of the Environment will be used to examine emission reduction scenarios, it is necessary to avoid parameterizations derived primarily from

calibration against field observations. As far as possible, the models will have to incorporate our state-of-the-art understanding of the processes involved in long-range transport. This will ensure credibility of the results from model simulations of scenarios quite different from the present.

Although the "validation" of a complex model will be difficult, the results from such a model cannot be attacked on scientific grounds. Furthermore, this type of model exhibits a much broader range of behaviour than a simple parameterized model. This information on system behaviour is necessary for decisions on emission control.

2.1 Objectives of Modeling System Development Program

The objectives of the program are:

1) To develop a comprehensive modeling system for assembling and executing model runs, and for archiving, displaying, and analyzing model results.
2) To develop mesoscale and LRT models to estimate concentrations and depositions of acidifying pollutants.
3) To evaluate the models against available observations and quantify the uncertainty associated with their predictions.
4) To develop a data base management system for emissions and meteorology which can be used to examine the effect of emission control strategies.

This system will satisfy the following requirements:

1) It will provide a comprehensive operating system which allows a non-specialist user to carry out routine modeling within a controlled user environment.
2) The models will incorporate, as far as possible, our latest understanding of the processes involved in long-range transport of pollutants.
3) The system will be designed to accommodate advances in the state-of-the-art.

2.2 Outstanding Technical Issues

The factors influencing long-range transport of pollution are discussed in detail in Volume I (prepared by MEP) and Volume II (prepared by ERT) of this report: the tables of contents of these two volumes are appended to this document. Here we highlight those processes which are generally believed to be the key to understanding acid deposition.

The construction of a realistic three-dimensional wind field from sparse observations has been shown to be important in estimating transport of pollution. Smith and Hunt (1978) and Eliassen (1982) emphasize the role of vertical wind shear in controlling horizontal dispersion. Lamb (1982) shows that assumptions about the unresolved velocity field can have a major effect on trajectories of air parcels. He and Slinn (1981) suggest that it is necessary to account for vertical advection in order to model scavenging processes realistically.

The modeling of vertical dispersion in the planetary boundary layer is crucial in the calculation of dry deposition. Slinn (1981) and Smith and Hunt (1978) show how elevated plumes are insulated from the ground during stable conditions. These plumes can travel large distances without being depleted by dry deposition. This transport is enhanced by the high wind speeds ($\sim$ 10-15 ms^{-1}) that occur in the nocturnal jet above the stable boundary layer (see Lamb 1982). These observations suggest that it is necessary to construct realistic models of dispersion and transport in the stable boundary layer.

Smith (1981) shows that the highly intermittent nature of rainfall can pose difficult problems in interpolating between observations of rainfall. His results indicate that wet deposition estimates are sensitive to the spacing of the rain gauge network used to derive the rainfall field. A related problem is that of the episodicity of rains. Smith (1981) shows for a site in southeastern England that 5.3% of the wet days in 1974 contributed about 30% of the annual wet deposition of sulfur. These results on the "patchiness" of rain suggest that it is necessary to construct a sophisticated model for rainfall interpolation.

The incorporation of non-linear chemistry into the LRT model is key to the usefulness of the model in examining emission scenarios. The problems associated with modeling complex chemistry are compounded by the effects of subgrid mixing on chemistry. Preliminary studies by Fisher (1979) and Lamb (1982) point to the necessity of accounting for this process in models. Although there has been some research in this important subject (see Murthy 1975) there is yet no convenient method of parameterizing subgrid scale effects in LRT models. This area will be given special attention during Phase II of this project.

There is increasing evidence (Heggs and Hobbs 1981) to show that in-cloud chemistry might have a controlling influence on the formation of acidifying species. Results from a simple cloud model proposed by Hong and Carmichael (1981) indicate that sulfate production rates in clouds can range from 60%/hr to 1,000%/hr. Similar results are obtained from an ERT study described in Chapter 6 of Volume II. These studies show that we will have to incorporate a realistic parameterization of cloud chemistry into the LRT model.

The evaluation of the models being developed is an important part of this project. Presently, this is an active area of research. Lamb (1982) has proposed some new ideas on this subject. Venkatram (1982) has done preliminary work on a conceptual framework which can be used to formulate methods to test models. In view of the proposed use of the LRT model, ERT/MEP will emphasize the development of methods to quantify uncertainty in model predictions.

3. SUMMARY OF WORK PLAN

The steps involved in achieving the objectives of the project are summarized below:

1) Develop an emissions, air quality, and meteorology data base management system and assemble the data sets required to run and evaluate the models.
2) Develop a land use and ground-cover data base for the grid system under consideration.
3) Develop routines to interpolate meteorological fields such as precipitation and cloud cover.
4) Develop a model to estimate micrometeorological variables at all grid points.
5) Develop a wind field model suitable for scales greater than 10 km. This model will be diagnostic and use available upper level and surface meteorological observations to create a three-dimensional gridded wind field.
6) Develop a submodel to estimate dry deposition of the various simulated pollutant species.
7) Develop a submodel to estimate wet scavenging of pollutants.
8) Develop models to simulate the chemistry of atmospheric pollutants in gas and aqueous phases.
9) Develop models to estimate vertical and horizontal diffusion of pollutants.
10) Test the wind field, dry deposition, wet deposition, and diffusion models against data.
11) Develop a numerical framework to solve the advection-diffusion equation on the grid system.
12) Assemble the models in the numerical framework.
13) Perform sensitivity tests on the model to identify critical processes.
14) Evaluate the model against observations.
15) Quantify uncertainty in model predictions.
16) Transfer the modeling system and associated model components to the MOE host computer.

Details of the work plan are given in the next section.

4. STATEMENT OF WORK AND SCHEDULE

4.1 Overview

Considerable effort has been expended in Phase I to define the specific tasks required to accomplish the program objectives. The specific tasks to be performed by MEP and ERT are discussed in Sections 4.2 and 4.3. Section 4.4 describes the proposed program schedule. Figure 1 gives summary schedules for the major project tasks: detailed schedules for all subtasks and associated activities are appended to this report. Tasks to be carried out by ERT and MEP are differentiated by prefix letters 'E' and 'M', respectively.

4.2 MEP Tasks Descriptions

Task M I: Development of Data Management System

All components of the Data Management System will be developed on MEP's in-house computer in Fortran IV (ANSI 77 standard) and tested. The components will be linked into a fully-operational system and tested. Figure 2 depicts the structure of the overall modeling system.

M I-1: Plan System Implementation.

M I-2: Flowchart Subsystems and Routines.

M I-3: Code, Test and Document Routines.

M I-4: Integrate System.

Flow diagrams and full details of each task, subtask and associated activities are given in Volume I of this report.

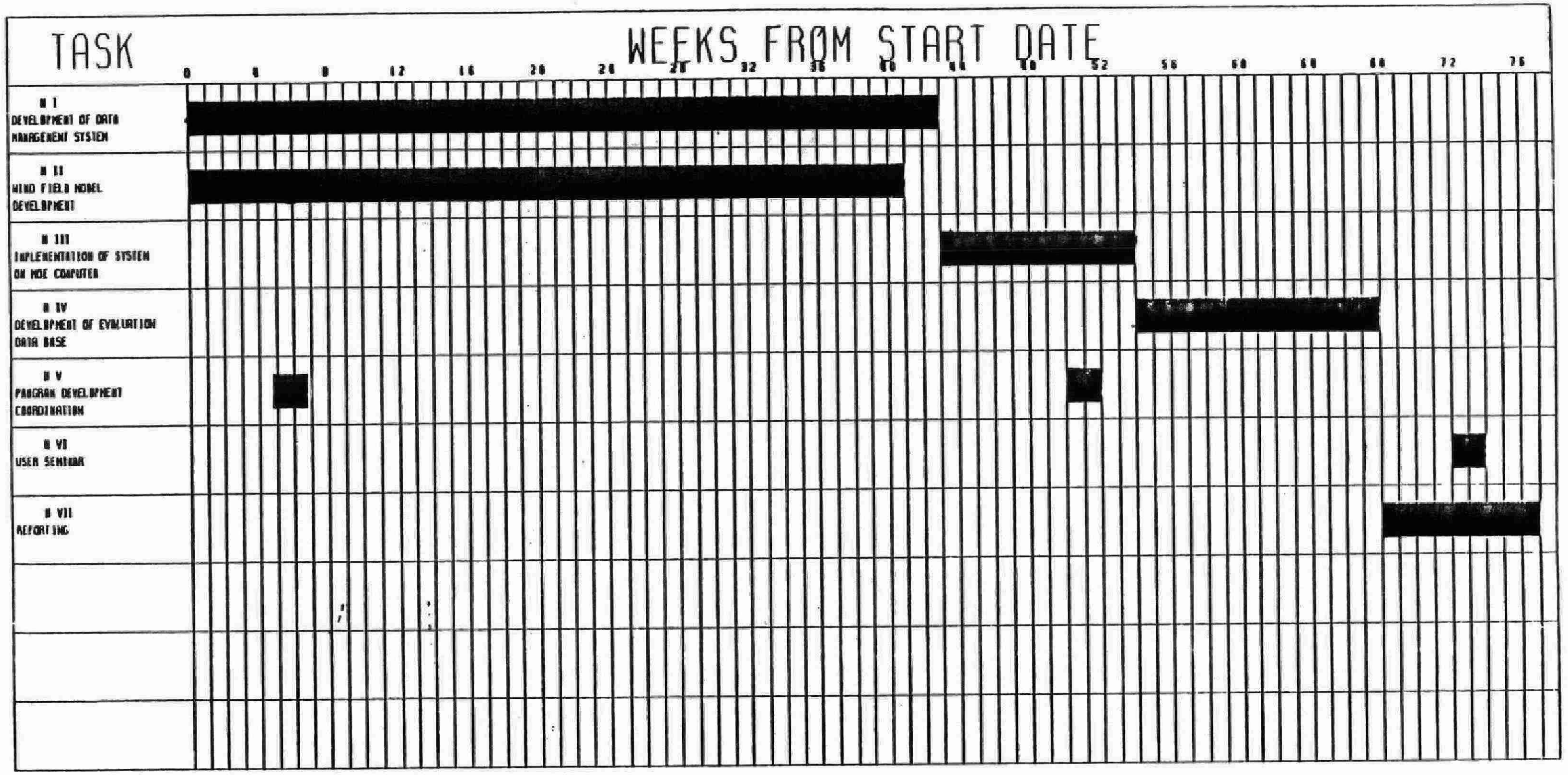
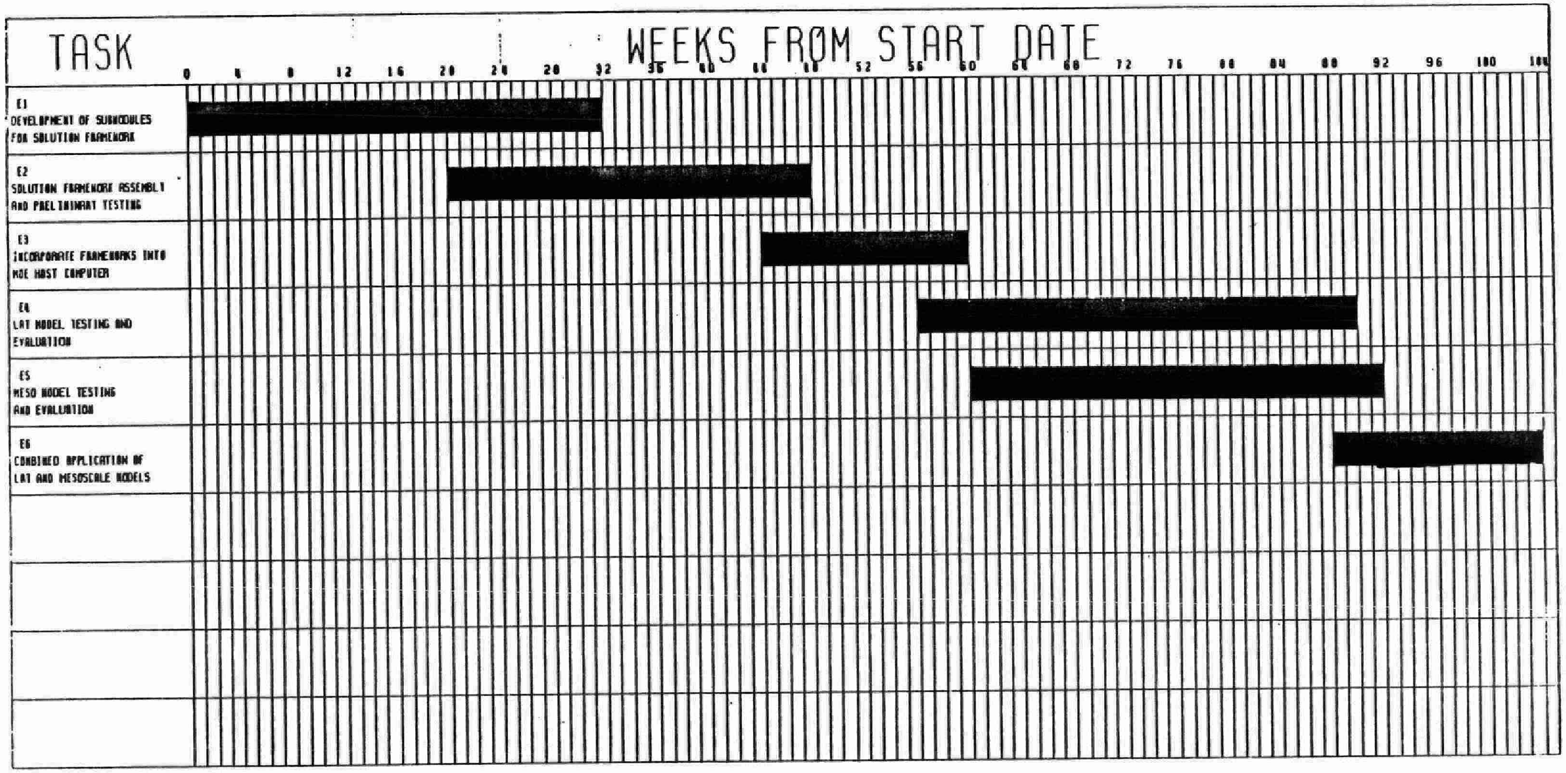


Figure 1 Summary Schedule for Executing Major Tasks



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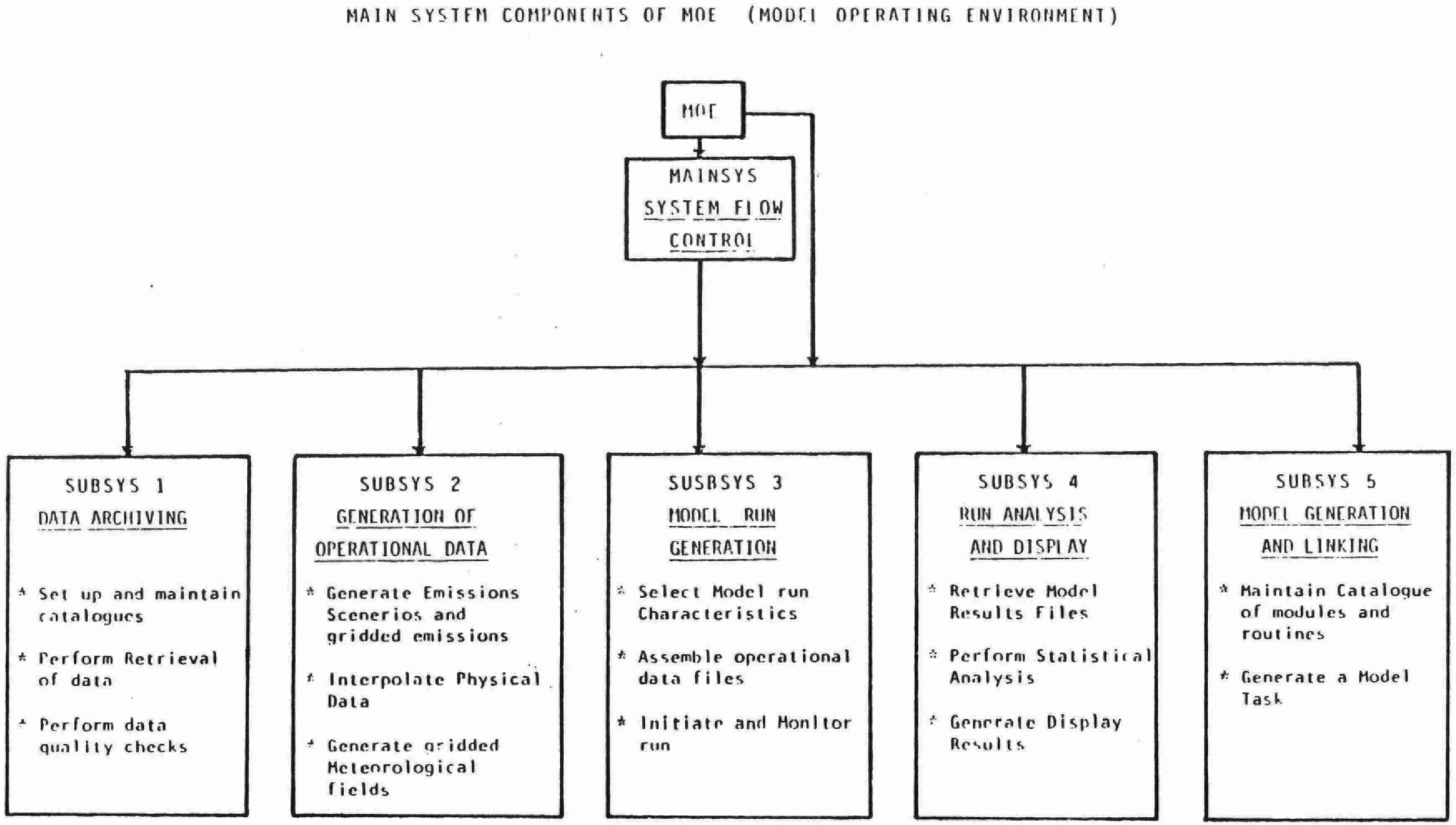

Figure 2 Overall Structure of Modeling System

Task M II: Wind Field Model Development

The wind field model components will be developed and individually tested on the MEP computer. The full model will be assembled and linked into the system.

M II-1: Objective Isentropic Upper-Air Analysis of Radiosonde Data.

M II-2: Processing of Canadian Meteorological Center (CMC) Analyses.

M II-3: Temporal Interpolation of Isentropic Upper-Air Analyses.

M II-4: Computation of Gridded Surface Geostrophic Winds.

M II-5: Atmospheric Boundary Layer Profiling.

M II-6: Determination of Ageostrophic Corrections.

M II-7: Nocturnal Jet Model Development.

M II-8: Rendering Wind Fields Mass Consistent.

M II-9: Topographic Perturbation of the Mesoscale Wind Field.

M II-10: Incorporation of Surface Wind Observations into Mesoscale Model.

M II-11: Main Line Program for Long-Range Model.

M II-12: Main Line Program for Mesoscale Model.

Task M III: Implementation of System on MOE Computer

The Data Management System and Wind Field Model Programs will be transferred to the MOE computing facility (presently not specified) and assembled. The dispersion and chemistry routines will be interfaced to the various subsystems.

The overall Data Management System and Wind Field model will be documented for the system user.

M III-1: Transfer Data Management System and Wind Field Model to MOE Computer.

M III-2: Interface Dispersion Model Routines.

M III-3: Document System and Wind Field Model.

Task M IV: Development of Evaluation Data Base

A representative period will be selected and all operational files for the wind field model assembled for the period. The wind field model will be tested for the generated data set.

M IV-1: Generate Operational Data for Selected Period.

M IV-2: Perform Test of Wind Field Model.

Task M V: Program Development Coordination

The system and computer code aspects of the implementation will be jointly defined with ERT and close coordination will be necessary to ensure total compatibility. This is an on-going activity with two milestones occurring during the detailed flowcharting and again in the system transfer and implementation phases.

Task M VI: User Seminar

The installed system will be documented for the user. In order to ensure rapid and efficient transfer of the system to MOE personnel, a seminar or series of seminars will be held to present and discuss the system.

Task M VII: Reporting

In addition to monthly program reports, a comprehensive final report on the project will be compiled. This report will include full documentation on the development and implementation of the Data Management System and the Wind Field model. A user's guide to the installed system, as well as a system maintenance manual, will be supplied as separate documents.

4.3 ERT Task Descriptions

Task E1: Development of Submodules for Solution Framework

E1-1: Dry Deposition Submodule. ERT will develop algorithms from the physical and micrometeorological data in SUBSYS 2, supplied by MEP (see Figure 2) to determine dry deposition velocities as a function of space and time for the simulated pollutants. The task will involve development of a second-level preprocessor in SUBSYS 2 to generate deposition velocity fields and guidelines for use of deposition velocities in the solution framework.

E1-2: Dispersion Submodule. ERT will develop algorithms to determine vertical and horizontal eddy diffusivity coefficients as a function of space and time from the micrometeorological, wind field, mixing height, and physical data in SUBSYS 2. The task will involve development of a second-level preprocessor in SUBSYS 2 to generate K_z and K_h fields and guidelines for use of the coefficients in the solution framework.

E1-3: Chemical Transformation Submodule. ERT will implement a gas-phase non-linear chemical kinetics model for the $SO_x/NO_x/RHC$ system. ERT will also develop an aqueous phase kinetics and equilibrium model for the S(IV), S(VI), O_3, H_2O_2, NO_3^-, NH_3, Ca, Na, H^+, CO_2 system that will be designed to operate in parallel with the gas-phase mechanism. In addition, ERT will exercise the PLMSTAR reactive plume model to investigate the effects of subgrid scale emission and concentration inhomogeneities on chemical transformation rates. Finally, ERT will develop an alternative simple chemical mechanism for SO_x/NO_x.

E1-4: Wet Removal Submodule. ERT will first incorporate the aqueous phase chemical mechanism into a cloud model. Extensive sensitivity tests will be performed using this complex wet removal model to parameterize chemical transformations in non-precipitating systems and effective scavenging rates and washout ratios for precipitating systems. The products from this task will be a second-level preprocessor for cloud and precipitation data in SUBSYS 2 and aqueous chemistry/wet removal submodules for the solution framework.

E1-5: Numerical Methods. ERT will implement numerical integration algorithms for advection, kinetics, and diffusion problems for use in the solution framework.

E1-6: Model Evaluation Statistics Package. ERT will develop post-processing algorithms to statistically evaluate model predictions with observations. These algorithms will be interfaced with the graphics/display post-processors by MEP.

E1-7: Submodule Documentation. ERT will prepare a report describing the specific formulations incorporated into the submodules and procedures for use of the algorithms in the model.

E1-8: Program Coordination and Meetings. ERT will frequently meet with MEP and OME to report progress, coordinate tasks, and resolve problems.

Task E2: Assembly and Preliminary Testing of the Solution Framework

E2-1: LRT Model Framework Assembly. ERT will design and implement the software of the LRT model. This involves designing the control logic input/output routines, data storage system, submodule calls, and data transfers of the solution framework.

E2-2: LRT Model Preliminary Testing. ERT will systematically test the functional operation of the LRT model on hypothetical data to ensure proper implementation.

E2-3: Mesoscale Model Framework Assembly. ERT will modify the LRT framework as necessary to construct the mesoscale model.

E2-4: Mesoscale Model Preliminary Testing. ERT will systematically test the functional operation of the mesoscale model on hypothetical data to ensure proper implementation.

E2-5: Program Coordination and Meetings. ERT will frequently meet with MEP and MOE to report progress, coordinate tasks, and resolve problems.

Task E3: Incorporate Frameworks on MOE Host Computer

E3-1: Transfer Codes and Establish Libraries. ERT will transfer the frameworks, associated submodules, and preliminary testing data to interface with the modeling systems on the host computer and catalog the files for operation within the MOE system.

E3-2: Test Framework-Only Operation on Preliminary Testing Data. ERT will repeat selected test cases to ensure that the software was transferred properly to the host computer.

E3-3: Test Framework Operation in MOE System. ERT will next test operation of the models using data generated by the MOE system to ensure all data are interfaced properly.

E3-4: Program Coordination and Meetings. Task E3 will require continuous coordination since it involves interfacing of the MEP and ERT software. ERT will meet with MEP and MOE as needed to coordinate this task and report on progress.

Task E4: LRT Model Testing and Evaluation

E4-1: Review of Archived Data. ERT will review the air quality, precipitation quality, meteorological, and emissions data sets incorporated by MEP into the data base. The purpose is to familiarize ourselves with the measurement coverage for different parameters, measurement uncertainties, emission inventory anomalies and other factors pertinent to model testing.

E4-2: LRT Case Study Selection. ERT will work jointly with MEP to select the modeling periods. ERT plans to select periods in several seasons with maximum data coverage. These study periods will then be separated into learning and testing cases.

E4-3: LRT Learning Set Event Simulation and Analysis. ERT will perform sensitivity studies using the learning set cases to refine model inputs for which there are little data and other modeling assumptions, so as to improve model agreement with observations.

E4-4: LRT Test Set Event Simulation and Analysis. ERT will perform simulations of the LRT test set cases using the protocol developed in Task E4-3.

E4-5: LRT Model Evaluation. ERT will statistically analyze the comparison of the LRT model predictions with observations.

E4-6: LRT Model Evaluation Documentation. ERT will prepare a report describing the learning and test case simulations and the evaluation of the model against observations.

E4-7: Program Coordination and Meetings. ERT will meet with MOE, MEP, and the Peer Review Committee to coordinate the program and report results.

Task E5: Mesoscale Model Testing and Evaluation

E5-1: Review of Archived Data. ERT will review the air quality, precipitation quality, meteorological, and emissions data sets incorporated by MEP into the data base.

E5-2: Mesoscale Case Study Selection. ERT will work jointly with MEP to select the modeling periods. ERT plans to select periods in several seasons with maximum data coverage. These study periods will then be separated into learning and testing cases.

E5-3: Mesoscale Learning Set Event Simulation and Analysis. ERT will perform sensitivity studies using the learning set cases to refine model inputs for which there are little data and other modeling assumptions, so as to improve model agreement with observations.

E5-4: Mesoscale Test Set Event Simulation and Analysis. ERT will perform simulations of the mesoscale test set cases using the protocol developed in Task E5-3.

E5-5: Mesoscale Model Evaluation. ERT will statistically analyze the comparison of the mesoscale model prediction with observations.

E5-6: Mesoscale Model Evaluation Documentation. ERT will prepare a report describing the learning and test case simulations and the evaluation of the model against observations.

E5-7: Program Coordination and Meetings. ERT will meet with MOE, MEP, and the Peer Review Committee to coordinate the program and report results.

Task E6: Combined Application of LRT and Mesoscale Models

E6-1: Case Selection. Since the study periods for the LRT and mesoscale model evaluation will likely be different (i.e., because of the maximum data availability criteria), several cases will be selected to illustrate the combined applications of the models.

E6-2: Simulation and Analysis. For these cases, the LRT model will be executed to define inflow boundary conditions for the mesoscale modeling region. The mesoscale model will then be executed using inflow concentrations generated from the archived data base and second using inflow concentrations from the LRT. Comparisons will be made to assess how dynamic boundary conditions affect the mesoscale modeling. Comparisons will be made between the mesoscale and LRT predictions for the mesoscale region. Also, an assessment will be made of how the mesoscale outflow concentration will effect the LRT model predictions.

E6-3: Combined LRT-Mesoscale Modeling Documentation. ERT will prepare a report documenting the results of the combined LRT-mesoscale modeling.

E6-4: Program Coordination and Meeting. ERT will meet with MOE, MEP, and the Peer Review Committee to coordinate the program and report the results.

4.4 Program Schedule

Figure 1 gives summary schedules for the major tasks and detailed schedules for the component subtasks are appended to this report. Briefly stated, development of the operating systems, data base management system, and models and implementation of the system on the host computer will require 15 months to complete. Testing and evaluation of the models will require an additional 9 months. Hence, the overall program will require 24 months to complete. Major milestones of the proposed program schedule include:

- Completion of the Operating and Data Base Management Systems;
- Completion of Data Set Archiving;
- Completion of Submodels;
- Completion of Solution Frameworks;
- Completion of Overall System Implementation on the Host Computer; and
- Completion of Model Evaluations.

Draft documentation covering the project work will be delivered as tasks are completed. These will be incorporated into a final report delivered at the end of the project.

5. PROJECT ORGANIZATION AND MANAGEMENT

To ensure successful and timely completion of this program, ERT and MEP are prepared to commit qualified personnel with broad experience in each of the task areas discussed in Section 4. The management plan has been designed to encourage maximum communication and cooperation between ERT, MEP, and MOE during the course of the study. This section describes the proposed management structure, key personnel, and management plan for the proposed study.

5.1 Organization and Key Personnel

The proposed project team consists of experienced managers, scientists, system analysts, and programmers. Their experience spans all of the disciplines relevant to a long-range and mesoscale model development program. Many scientists on the project have internationally recognized reputations for their work in meteorology and chemistry. The organization of the project team is shown schematically in Figure 3.

Mr. Thomas Lavery, Manager of Applied Research in the ERT Physical Sciences Center, and Dr. Boris Weisman, Vice-President of MEP, will serve as co-project directors and have overall responsibility for completion of the program. Mr. Lavery and Dr. Weisman have extensive experience in managing large air quality programs involving urban, mesoscale, and LRT modeling.

Dr. Akula Venkatram, Senior Consulting Scientist at ERT and Dr. M. Trevor Scholtz, Director of the Consulting Service Division at MEP, will serve as co-project managers. They have responsibility for both technical direction and day-to-day management of the program. Drs. Venkatram and Scholtz have extensive experience in air pollution meteorology and LRT modeling.

The project staff from ERT's Applied Research Organization include: Dr. Robert Yamartino (Senior Air Quality Scientist) who will be involved in numerical methods, dry deposition, model framework design, and model testing; Dr. Alan Lloyd (Manager, Westlake Office) who will be responsible for gas and aerosol chemistry;

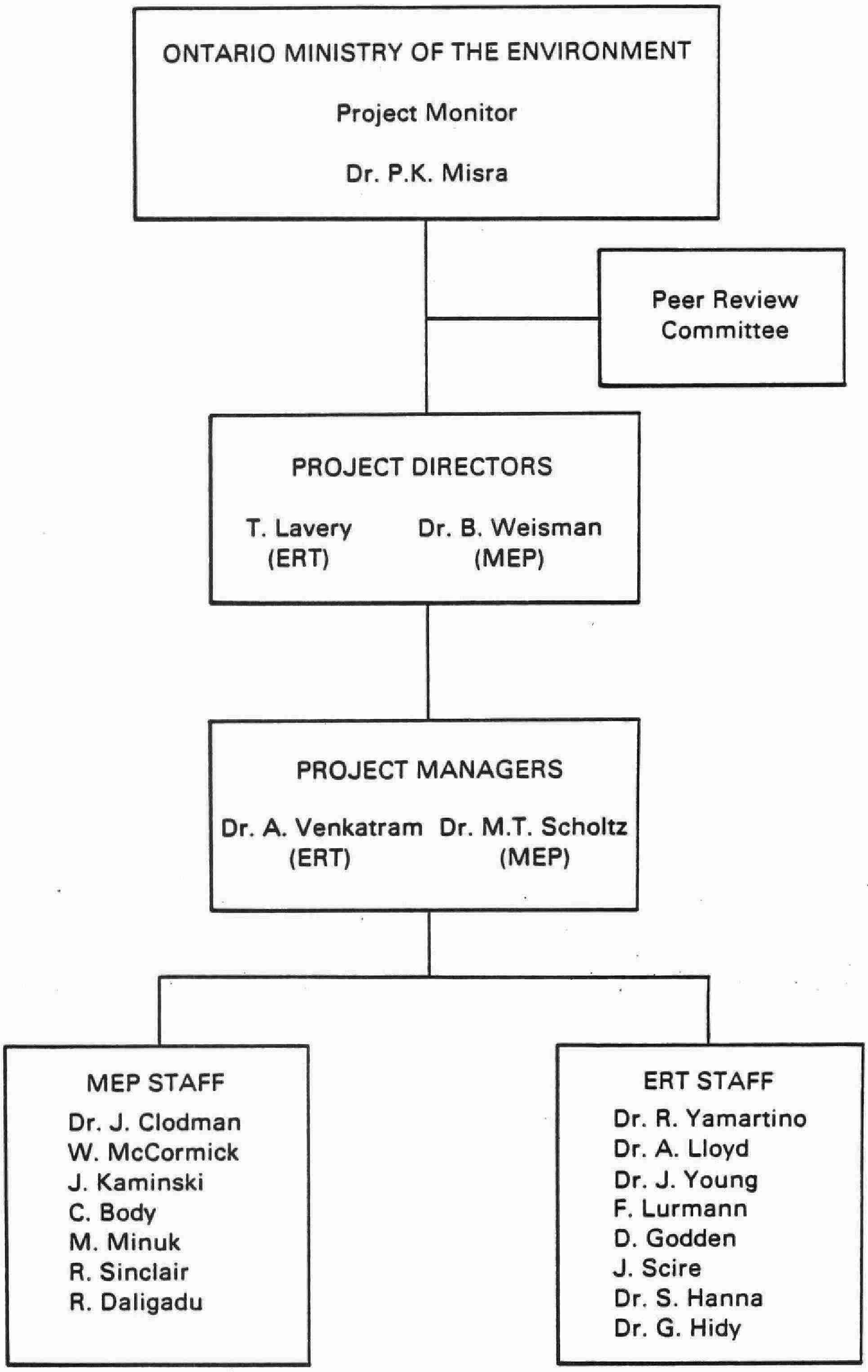

Figure 3 Technical Management and Personnel Structure

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Dr. James Young (Senior Air Quality Scientist) who will be responsible for aqueous phase chemistry involved in wet removal submodule design; Mr. Fred Lurmann (Scientific Advisor) who will be responsible for chemical and wet removal software implementation, model framework implementation in host computer, and model testing; Mr. Daniel Godden (Meteorologist) who will be involved in dispersion submodule implementation and model testing; Mr. Joseph Scire (Meteorologist) will be involved in dry deposition and wet removal submodule implementation, and model testing; and Dr. Steve Hanna (Principal Meteorologist) and Dr. George Hidy (Vice President and Chief Scientist - Atmospheric Chemistry) will provide internal review of the program.

The project staff at MEP includes Dr. Joseph Clodman (Senior Scientist), Mr. Warren McCormick (Scientist), Mr. Jack Kaminski (Scientist), Mr. Christopher Body (Scientist), Mr. Michael Minuk (Systems Analyst), Mr. Raymond Sinclair (Systems Analyst), and Mr. Ron Daligadu (Analyst/Programmer). The MEP staff will be subdivided into scientists and systems analysts dedicated to the data base management system development and meteorological preprocessor design and testing.

The technical work to be accomplished in the development effort will be undertaken primarily by these senior scientists and not by junior personnel. This major commitment of senior scientists will ensure a superior technical product as well as cost- and schedule-saving advantages to the Ontario Government.

5.2 Progress Reviews and Reports

In order to coordinate and manage the program properly, task managers will be assigned to the major components of the proposed program. These assignments, along with a monthly progress review by the project directors and corporate management, will ensure continuous progress toward the study goals. The project directors, project managers, and task leaders will use computer-based financial and budgetary systems to review project labor costs and person-hour expenditures on a weekly basis and other direct costs, such as computer and travel, on a monthly basis. Labor and dollar

expenditures will be compared to those projected in the proposed study schedule and costs allocation.

Joint ERT and MEP monthly technical progress reports will be submitted to the Ontario Ministry of the Environment. These monthly reports will contain five sections:

- Section I - An introduction covering the purpose and scope of the contract effort.
- Section II - A description of overall progress plus a separate description for each task or other logical segment of work for which effort was expended during the work period.
- Section III - A description of current problems that may impede performance along with proposed corrective action.
- Section IV - A description of work to be performed during the next reporting period.
- Section V - A contract cost summary comparing total contract costs projected by month and the actual contract costs as of the date of the activity (submitted separately by ERT and MEP).

Within 30 calendar days after the completion of the technical effort specified in the contract, ERT and MEP will submit for review two copies each of the draft final report, the proposed User's Guides to the modeling system, and the project summary. The draft reports will document in detail all of the work performed under the contract, including data, analyses, and interpretations, as well as recommendations and conclusions based on the results obtained.

5.3 Corporate Management Procedures

The successful achievement of the goals in this program depends on three areas: technical quality and thoroughness, accurate scheduling, and minimized cost. ERT and MEP's management control is designed to account for each of these areas. To implement project control, ERT and MEP have established the overall goals and identified intermediate tasks and schedule milestones. These have been combined into a master program schedule.

Using such a scheme, the project managers can implement and guide each part of the overall study toward the goals. The program schedule serves as a guideline for reporting progress to management and to MOE.

The technical and fiscal progress of projects is reported monthly to ERT and MEP vice presidents to provide corporate management with a record of the achievements in the study and to resolve problems as they develop.

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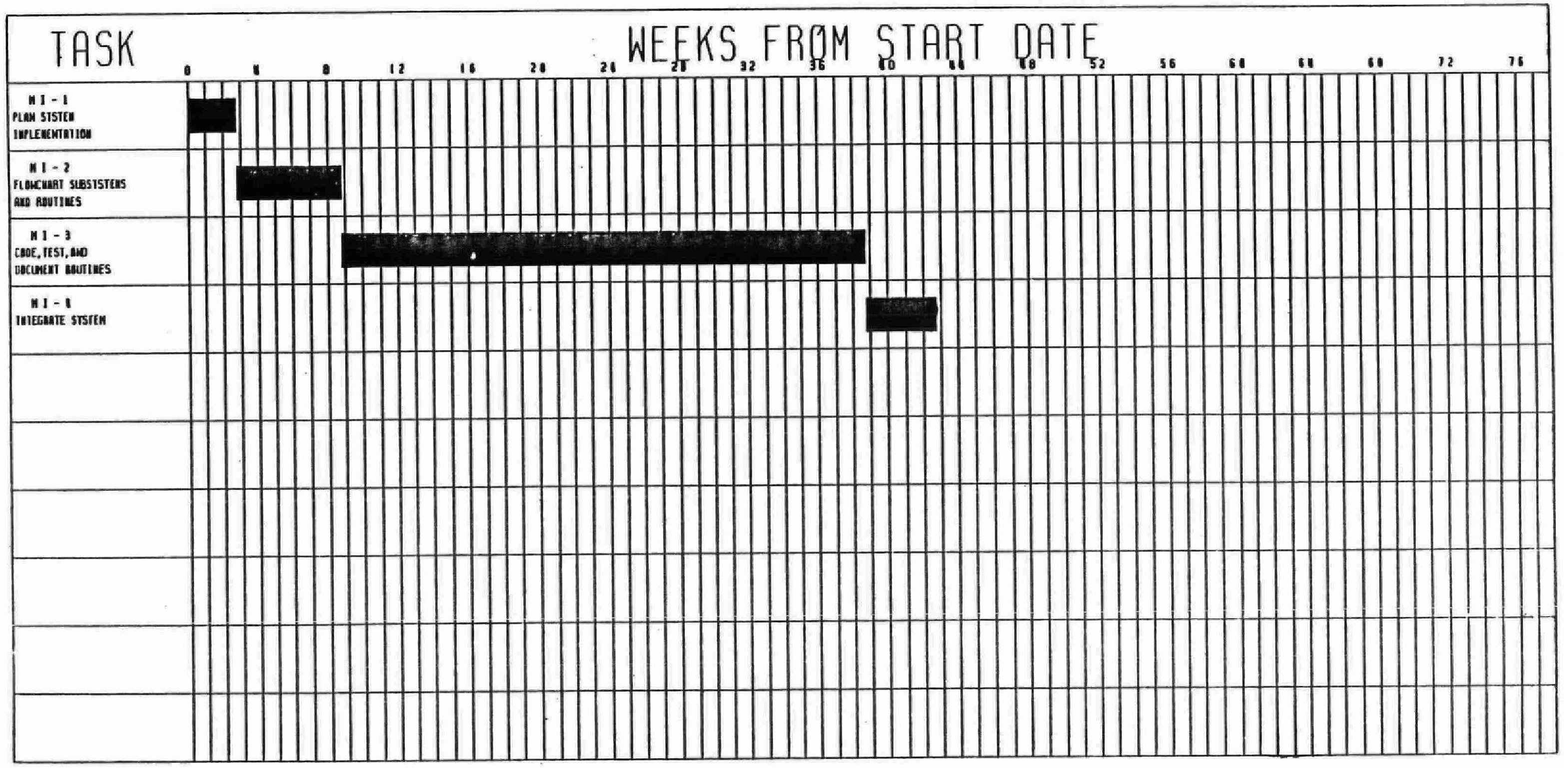
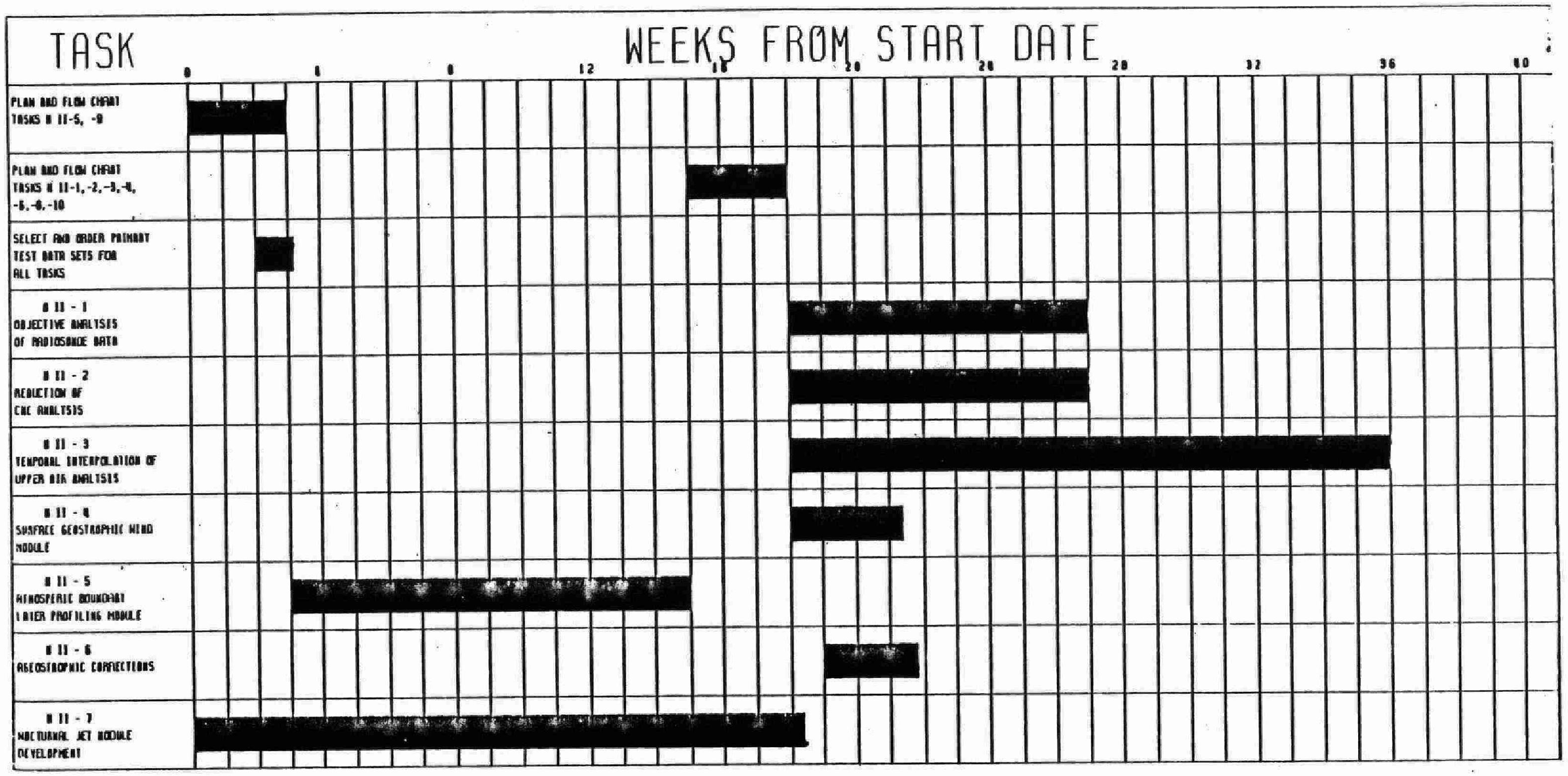
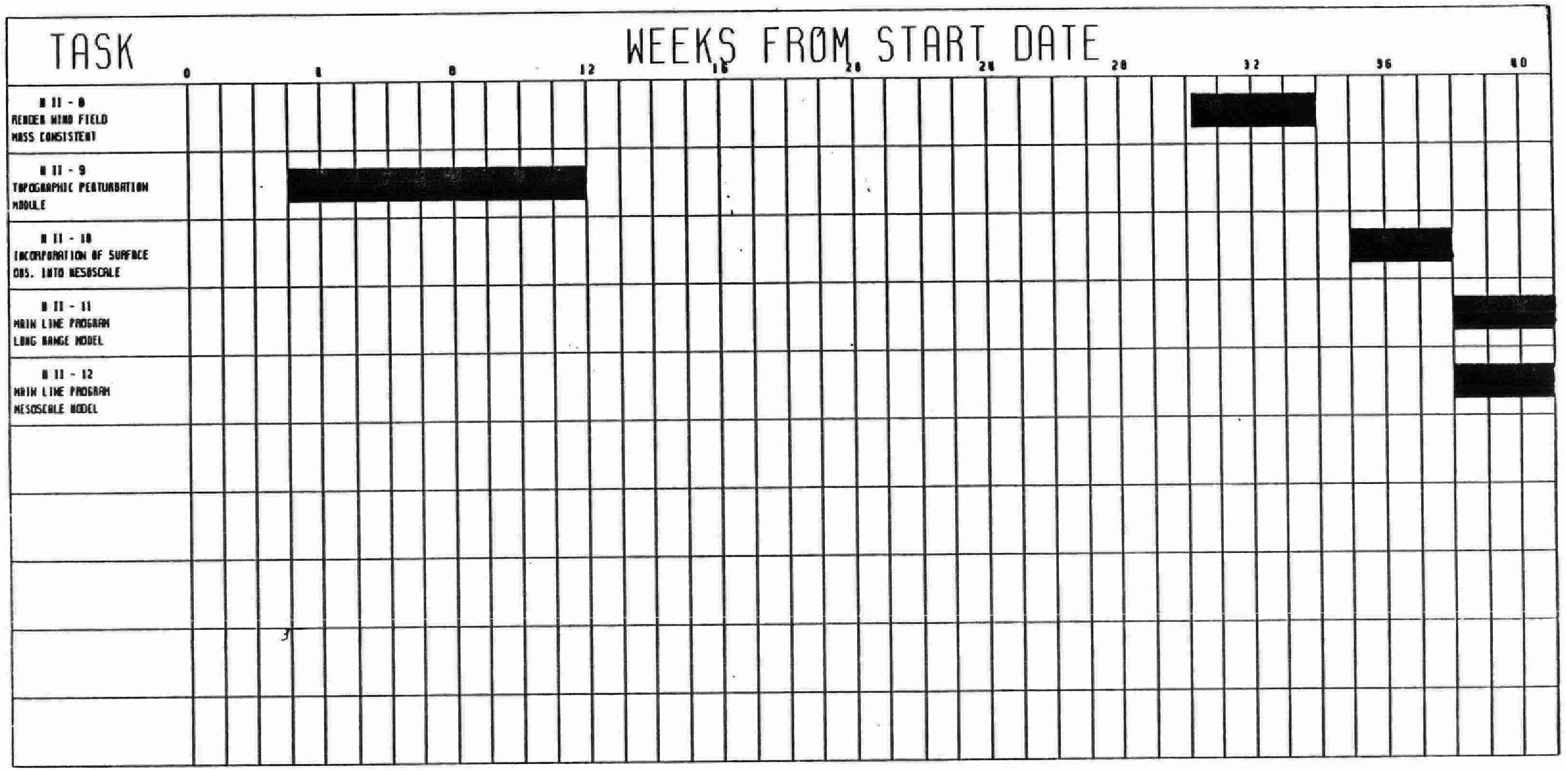
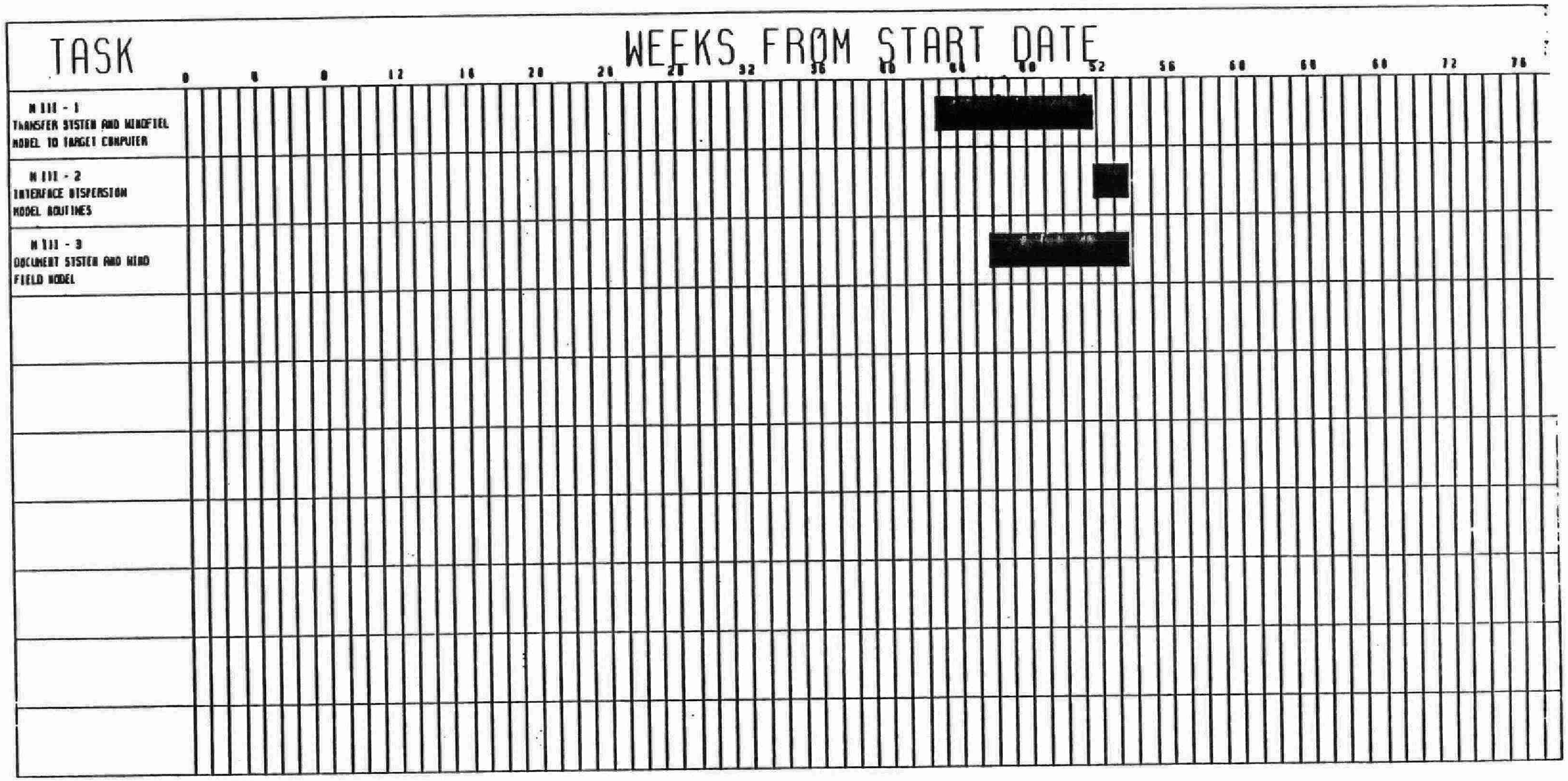
APPENDIX B

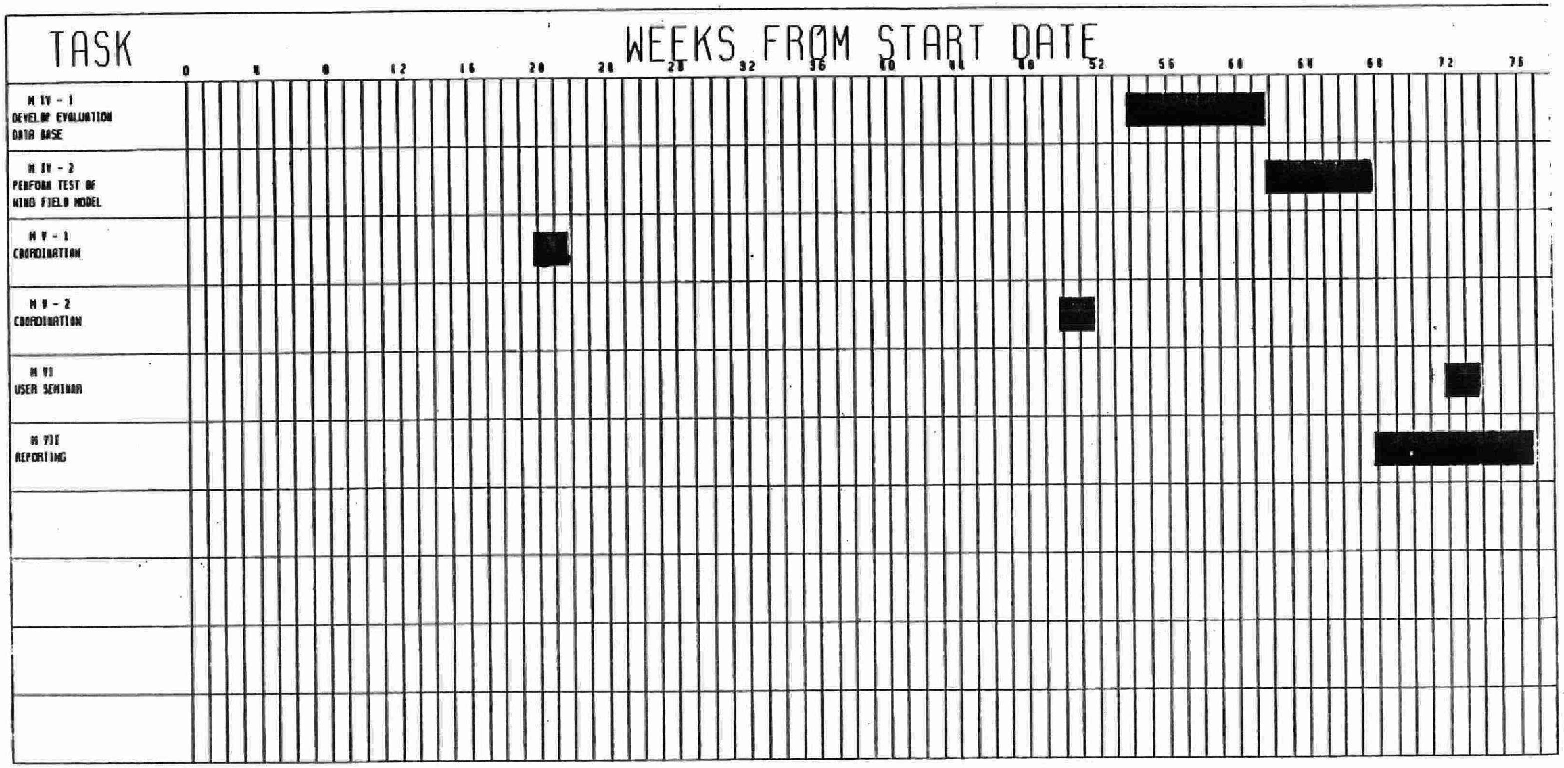
SCHEDULE FOR EXECUTING COMPONENT SUBTASKS

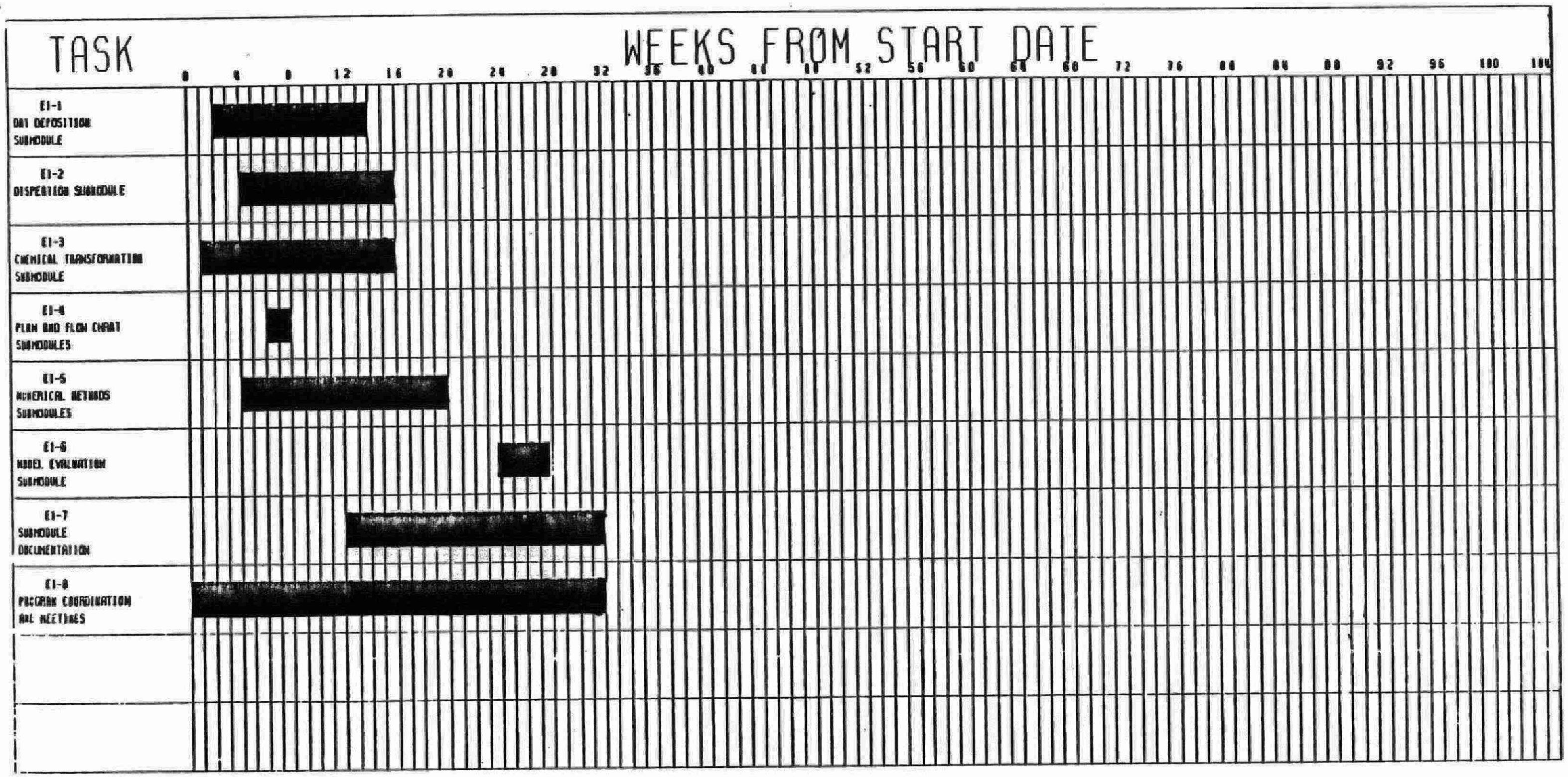

TASK
WEEKS FROM START DATE
12
16
20
24
32
36
52
56
72
76
MI-1
PLAN SYSTEM IMPLEMENTATION
MI-2
FLOWCHART SUBSYSTEMS AND ROUTINES
MI-3
CODE, TEST, AND DOCUMENT ROUTINES
MI-4
INTEGRATE SYSTEM

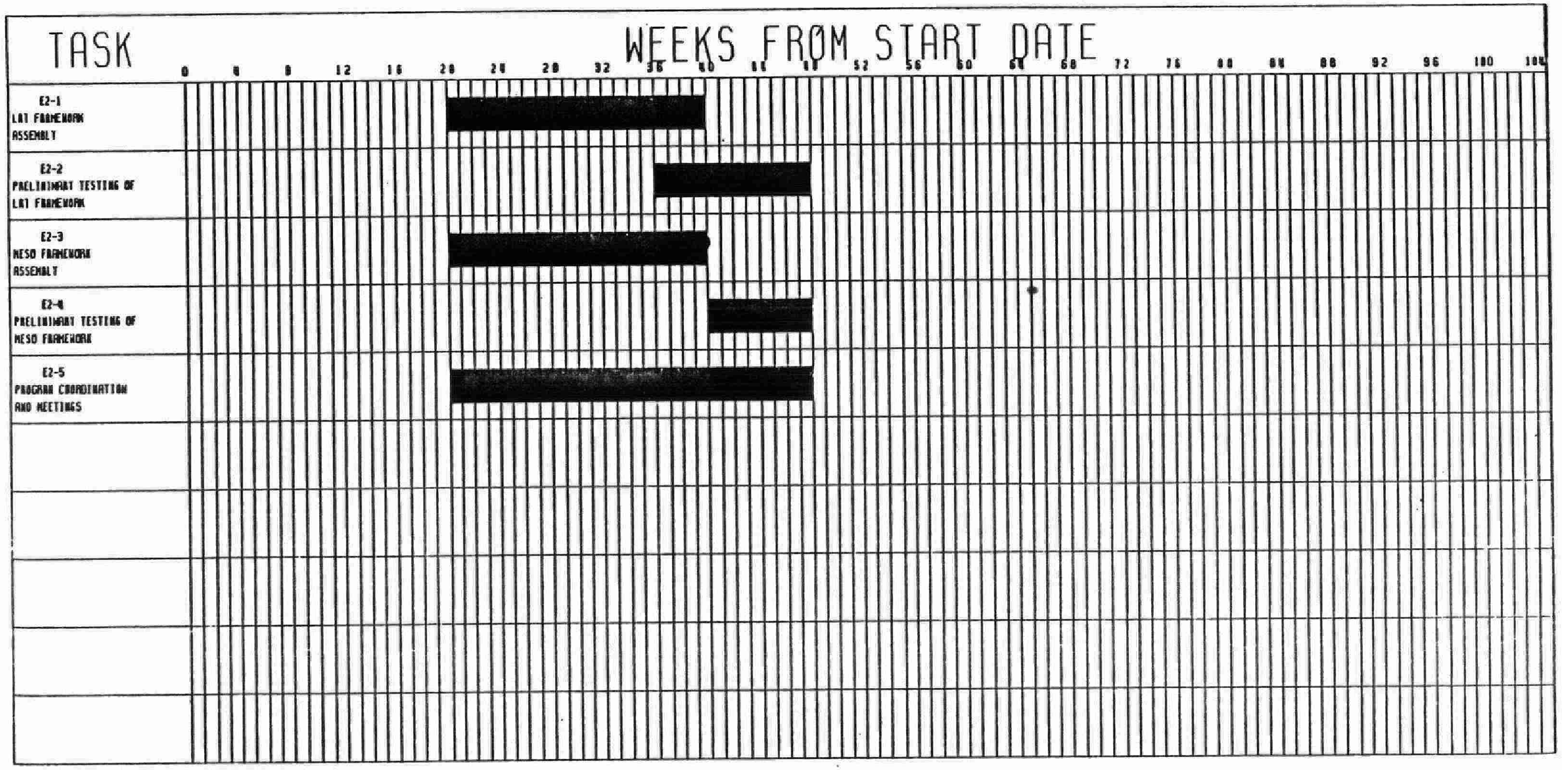

TASK
WEEKS FROM START DATE
0
4
8
12
16
20
24
28
32
36
40
PLAN AND FLOW CHART TASKS # II-5, -9
PLAN AND FLOW CHART TASKS # II-1, -2, -3, -4, -6, -8, -10
SELECT AND ORDER PRIMARY TEST DATA SETS FOR ALL TASKS
II - 1 OBJECTIVE ANALYSIS OF RADIOSONDE DATA
II - 2 REDUCTION OF CNC ANALYSIS
II - 3 TEMPORAL INTERPOLATION OF UPPER AIR ANALYSIS
II - 4 SURFACE GEOSTROPHIC WIND MODULE
II - 5 ATMOSPHERIC BOUNDARY LAYER PROFILING MODULE
II - 6 AGEOSTROPHIC CORRECTIONS
II - 7 NOCTURNAL JET MODULE DEVELOPMENT

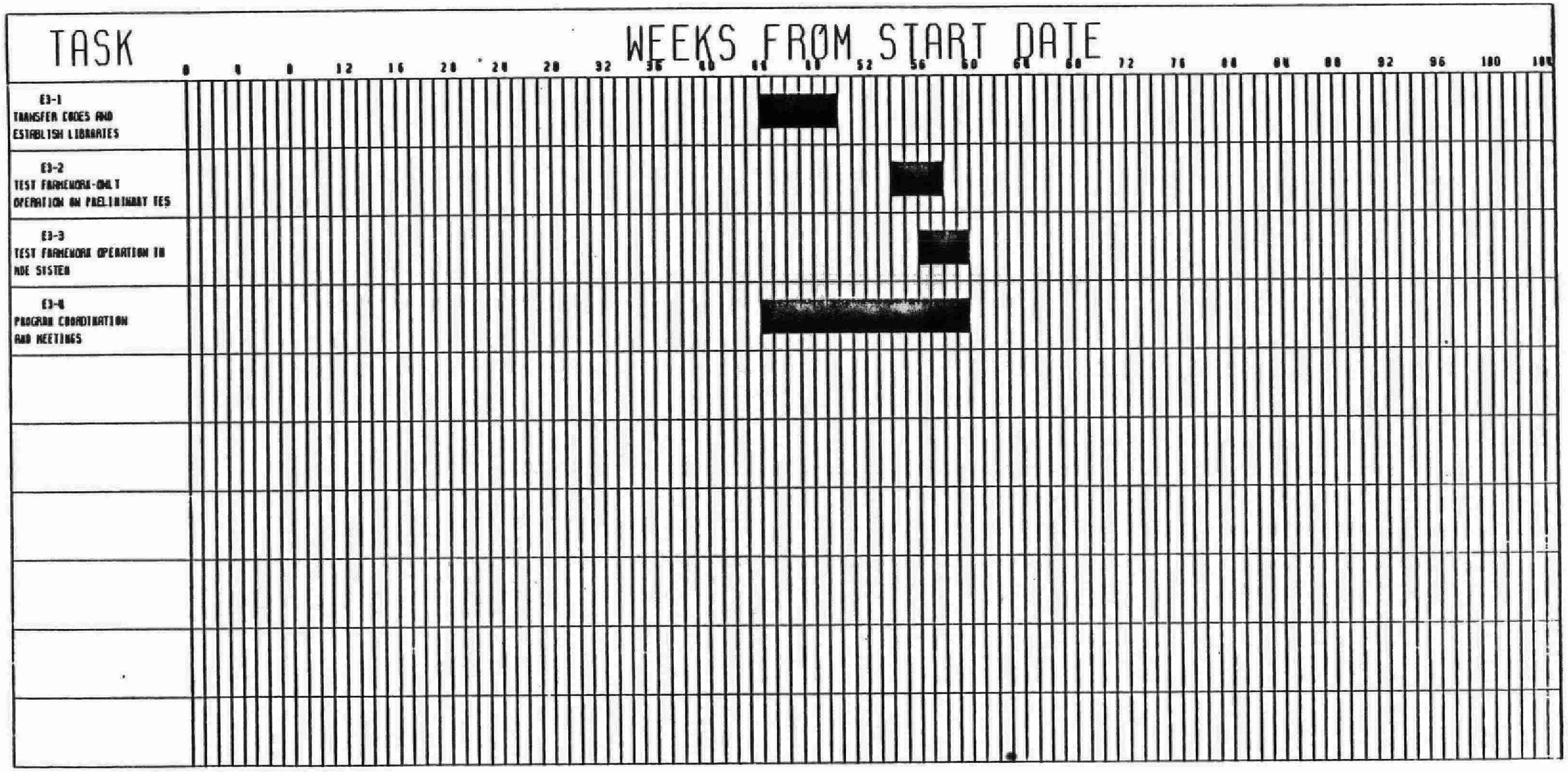

TASK
WEEKS FROM START DATE
0
4
8
12
16
20
24
28
32
36
40
M II - 8
RENDER WIND FIELD
MASS CONSISTENT
M II - 9
TOPOGRAPHIC PERTURBATION
MODULE
M II - 10
INCORPORATION OF SURFACE
OBS. INTO MESOSCALE
M II - 11
MAIN LINE PROGRAM
LONG RANGE MODEL
M II - 12
MAIN LINE PROGRAM
MESOSCALE MODEL


TASK
WEEKS FROM START DATE
12
32
52
56
72
76
M III - 1
TRANSFER SYSTEM AND WINDFIEL
MODEL TO TARGET COMPUTER
M III - 2
INTERFACE DISPERSION
MODEL ROUTINES
M III - 3
DOCUMENT SYSTEM AND WIND
FIELD MODEL

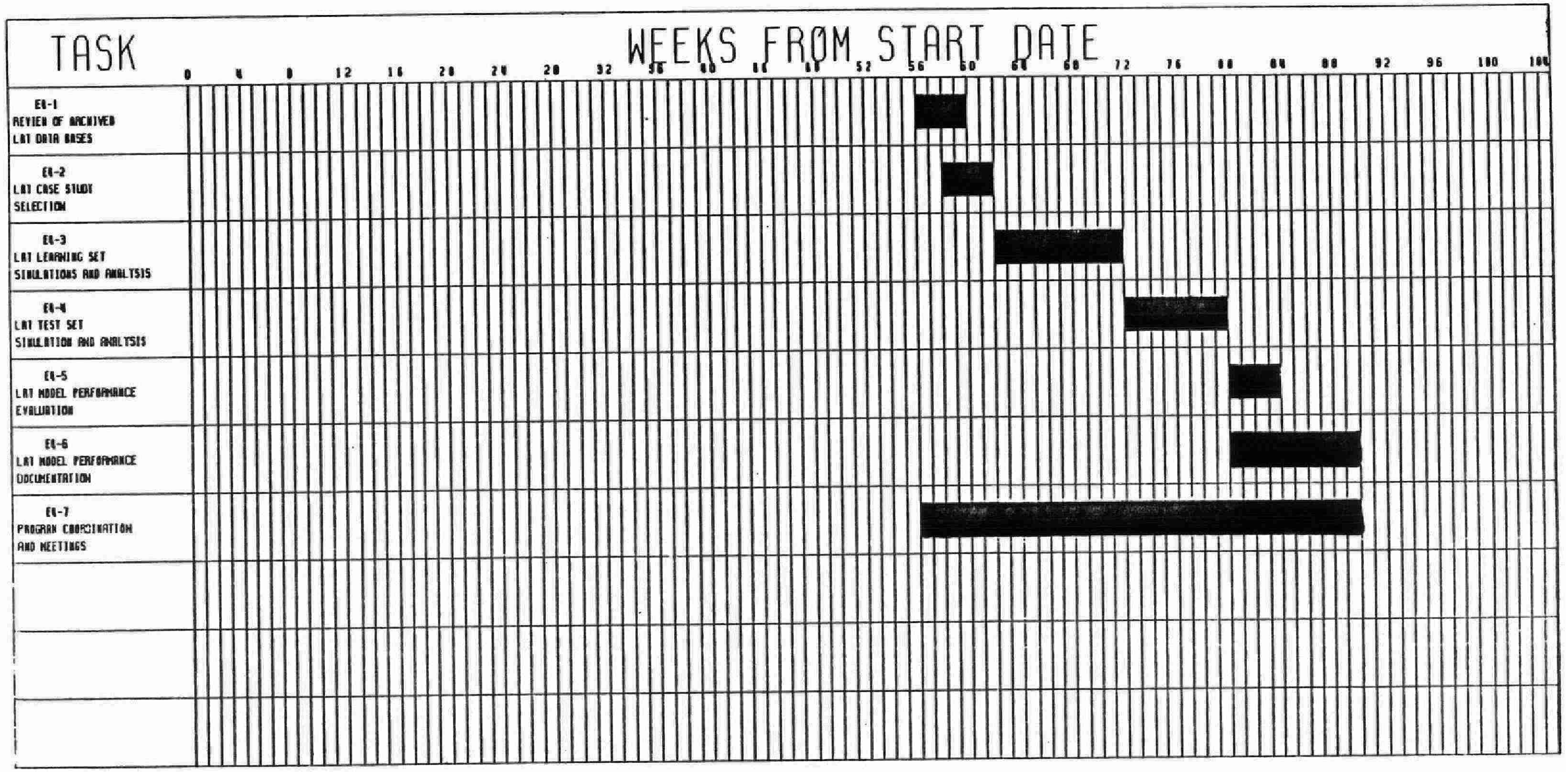

TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76
M IV - 1
DEVELOP EVALUATION
DATA BASE
M IV - 2
PERFORM TEST OF
WIND FIELD MODEL
M V - 1
COORDINATION
M V - 2
COORDINATION
M VI
USER SEMINAR
M VII
REPORTING

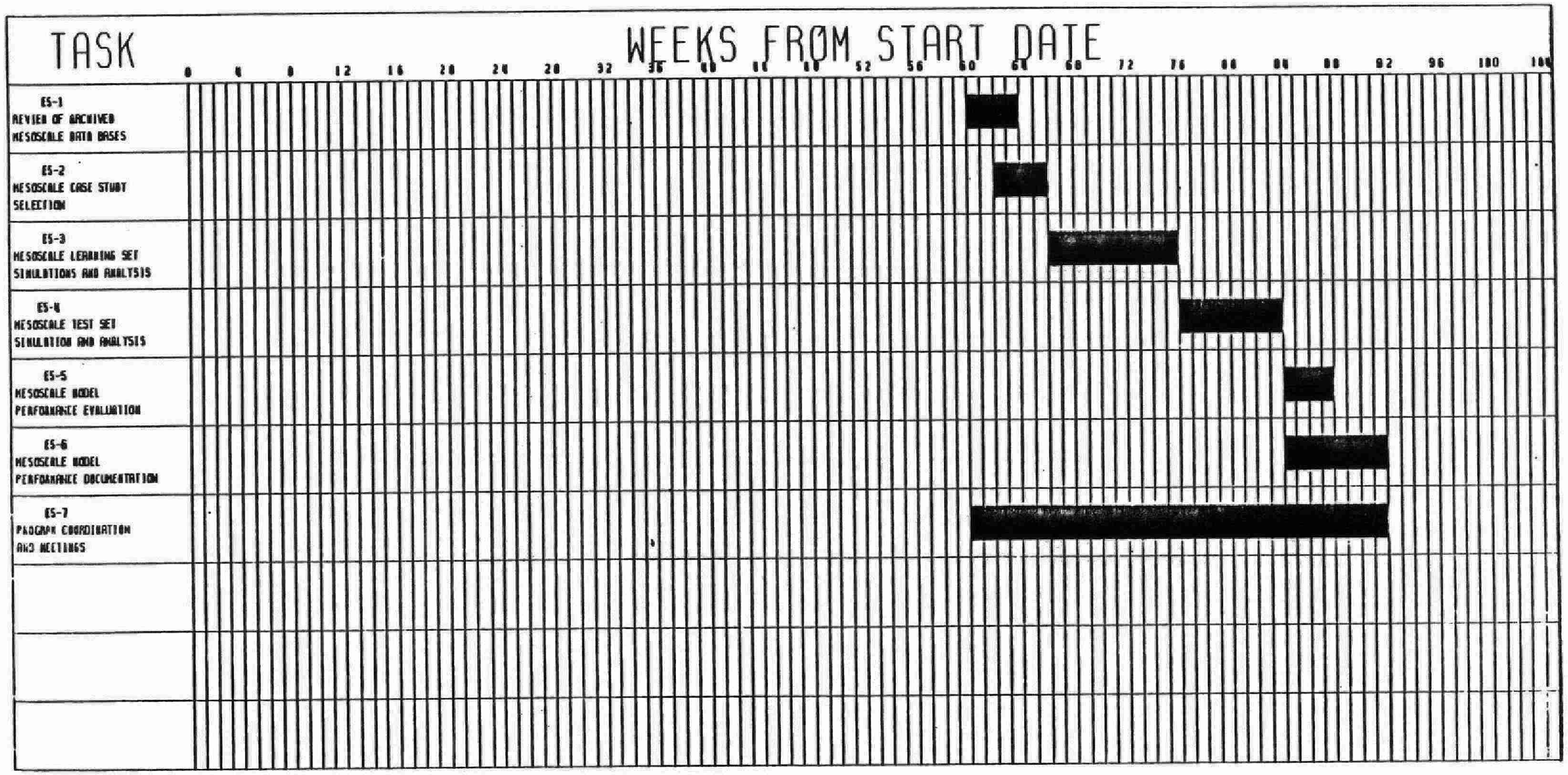

TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 104
E1-1
DRY DEPOSITION SUBMODULE
E1-2
DISPERSION SUBMODULE
E1-3
CHEMICAL TRANSFORMATION SUBMODULE
E1-4
PLAN AND FLOW CHART SUBMODULES
E1-5
NUMERICAL METHODS SUBMODULES
E1-6
MODEL EVALUATION SUBMODULE
E1-7
SUBMODULE DOCUMENTATION
E1-8
PROGRAM COORDINATION AND MEETINGS

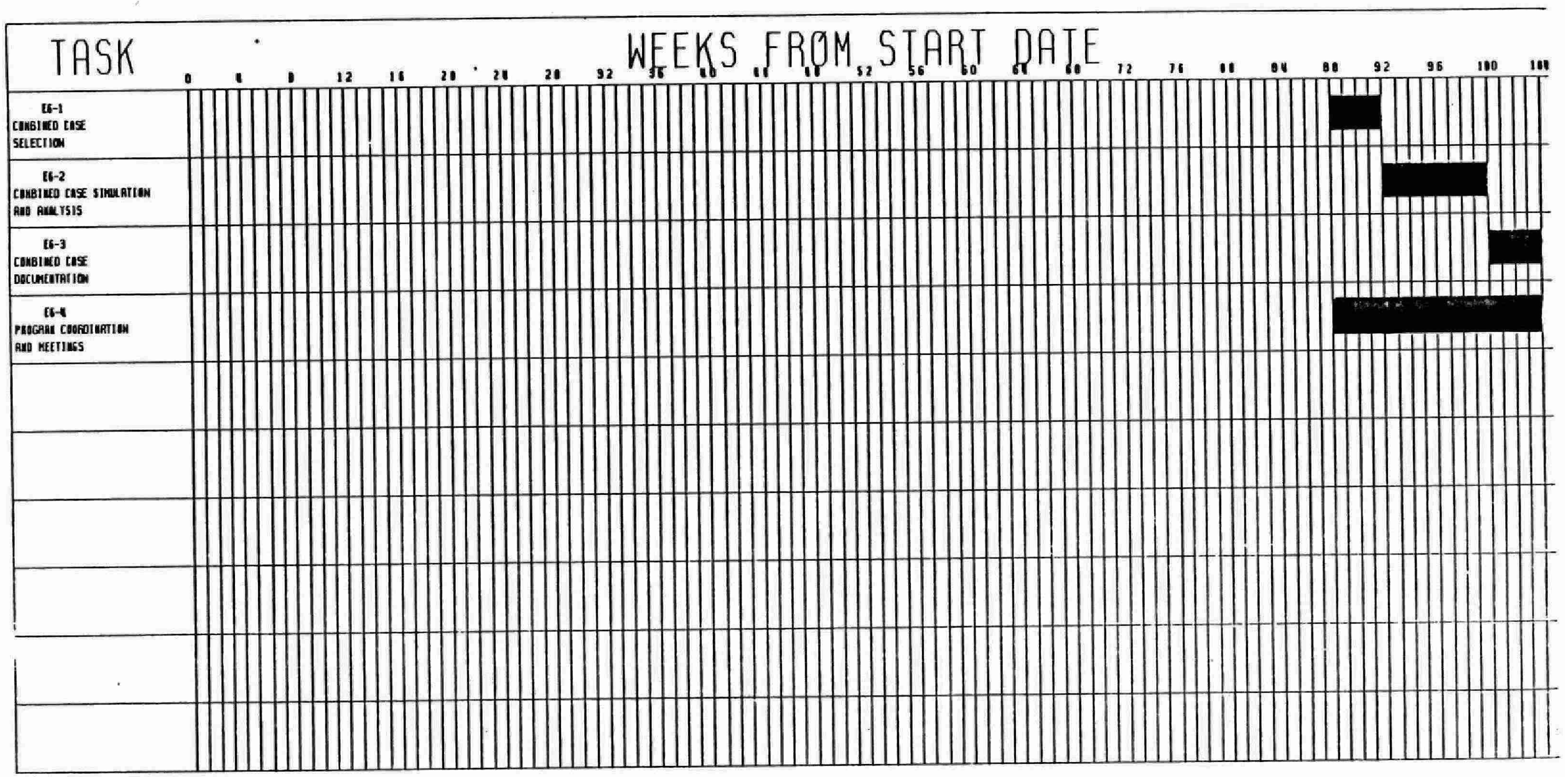

TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 104
E2-1
LAT FRAMEWORK
ASSEMBLY
E2-2
PRELIMINARY TESTING OF
LAT FRAMEWORK
E2-3
MESO FRAMEWORK
ASSEMBLY
E2-4
PRELIMINARY TESTING OF
MESO FRAMEWORK
E2-5
PROGRAM COORDINATION
AND MEETINGS



TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 104
E3-1
TRANSFER CODES AND
ESTABLISH LIBRARIES
E3-2
TEST FRAMEWORK-ONLY
OPERATION ON PRELIMINARY TES
E3-3
TEST FRAMEWORK OPERATION IN
NDE SYSTEM
E3-4
PROGRAM COORDINATION
AND MEETINGS

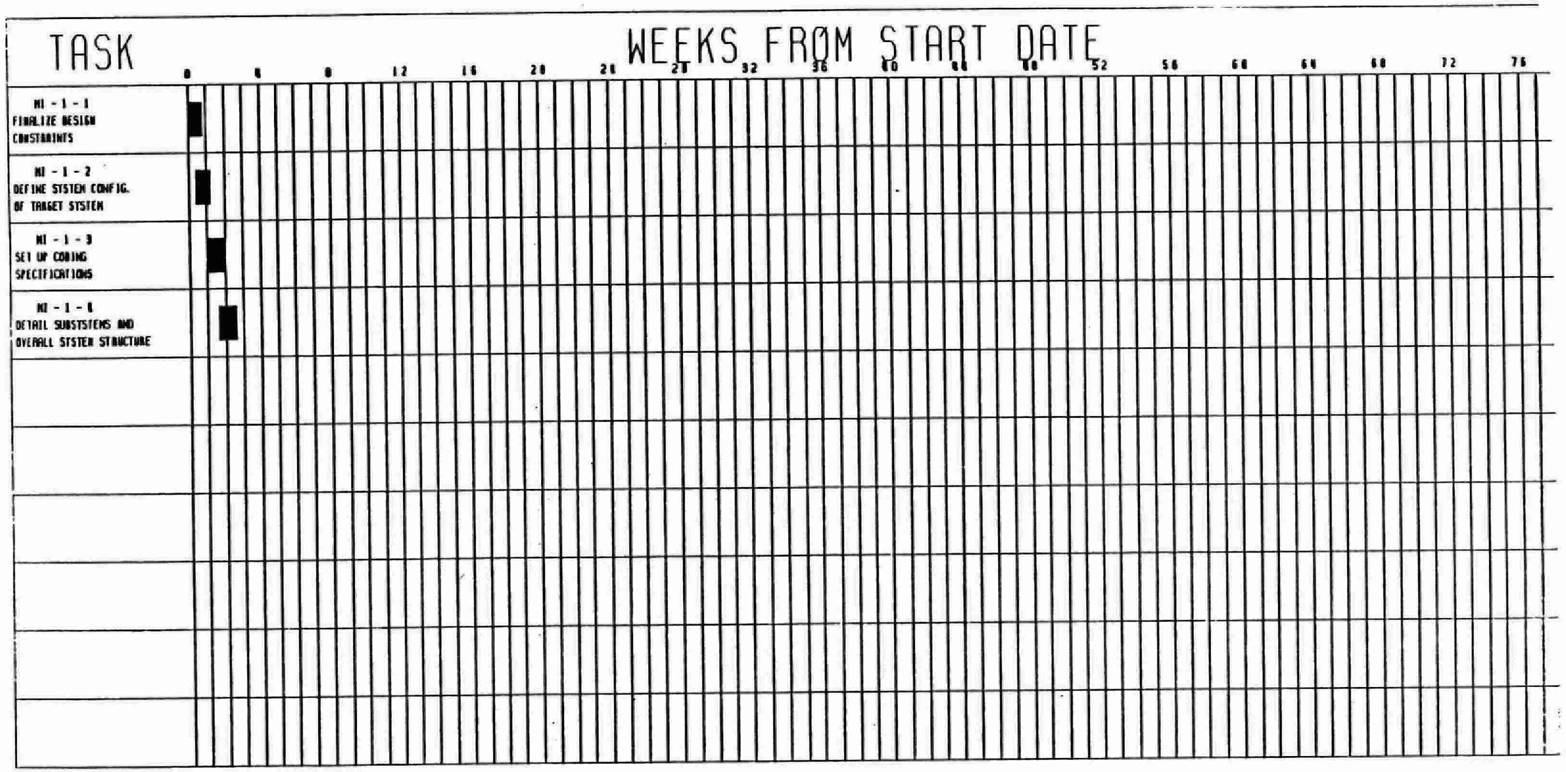

TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 104
E4-1
REVIEW OF ARCHIVED
LAT DATA BASES
E4-2
LAT CASE STUDY
SELECTION
E4-3
LAT LEARNING SET
SIMULATIONS AND ANALYSIS
E4-4
LAT TEST SET
SIMULATION AND ANALYSIS
E4-5
LAT MODEL PERFORMANCE
EVALUATION
E4-6
LAT MODEL PERFORMANCE
DOCUMENTATION
E4-7
PROGRAM COORDINATION
AND MEETINGS


TASK
WEEKS FROM START DATE
12
16
20
24
28
32
52
56
60
72
76
92
96
100
ES-1
REVIEW OF ARCHIVED
MESOSCALE DATA BASES
ES-2
MESOSCALE CASE STUDY
SELECTION
ES-3
MESOSCALE LEARNING SET
SIMULATIONS AND ANALYSIS
ES-4
MESOSCALE TEST SET
SIMULATION AND ANALYSIS
ES-5
MESOSCALE MODEL
PERFORMANCE EVALUATION
ES-6
MESOSCALE MODEL
PERFORMANCE DOCUMENTATION
ES-7
PROGRAM COORDINATION
AND MEETINGS


TASK
WEEKS FROM START DATE
0
12
16
20
28
32
52
56
60
72
76
84
88
92
96
100
E6-1
COMBINED CASE
SELECTION
E6-2
COMBINED CASE SIMULATION
AND ANALYSIS
E6-3
COMBINED CASE
DOCUMENTATION
E6-4
PROGRAM COORDINATION
AND MEETINGS

APPENDIX C

DETAILED SCHEDULE FOR ACTIVITIES WITHIN TASKS AND SUBTASKS


TASK
WEEKS FROM START DATE
0
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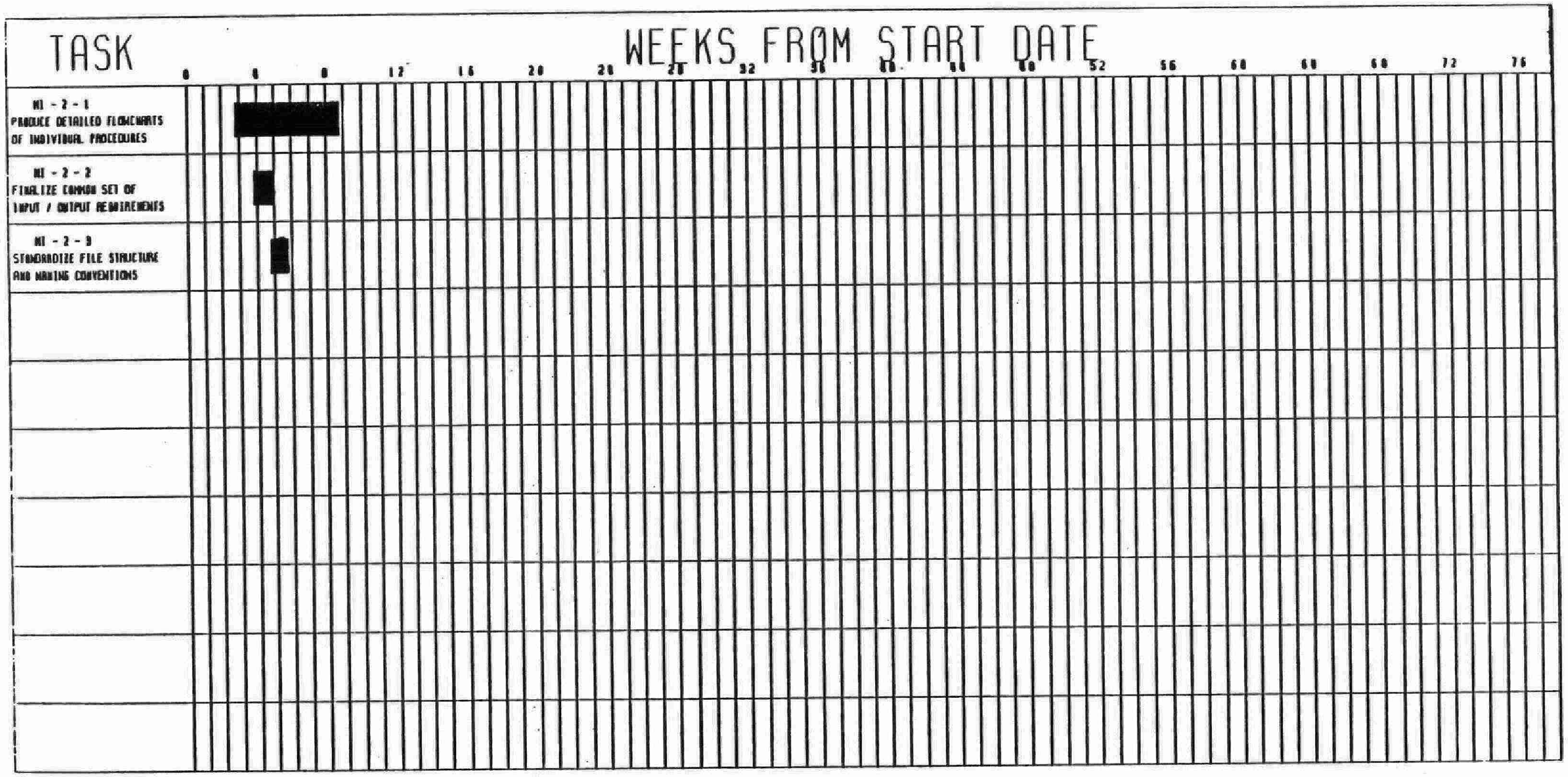
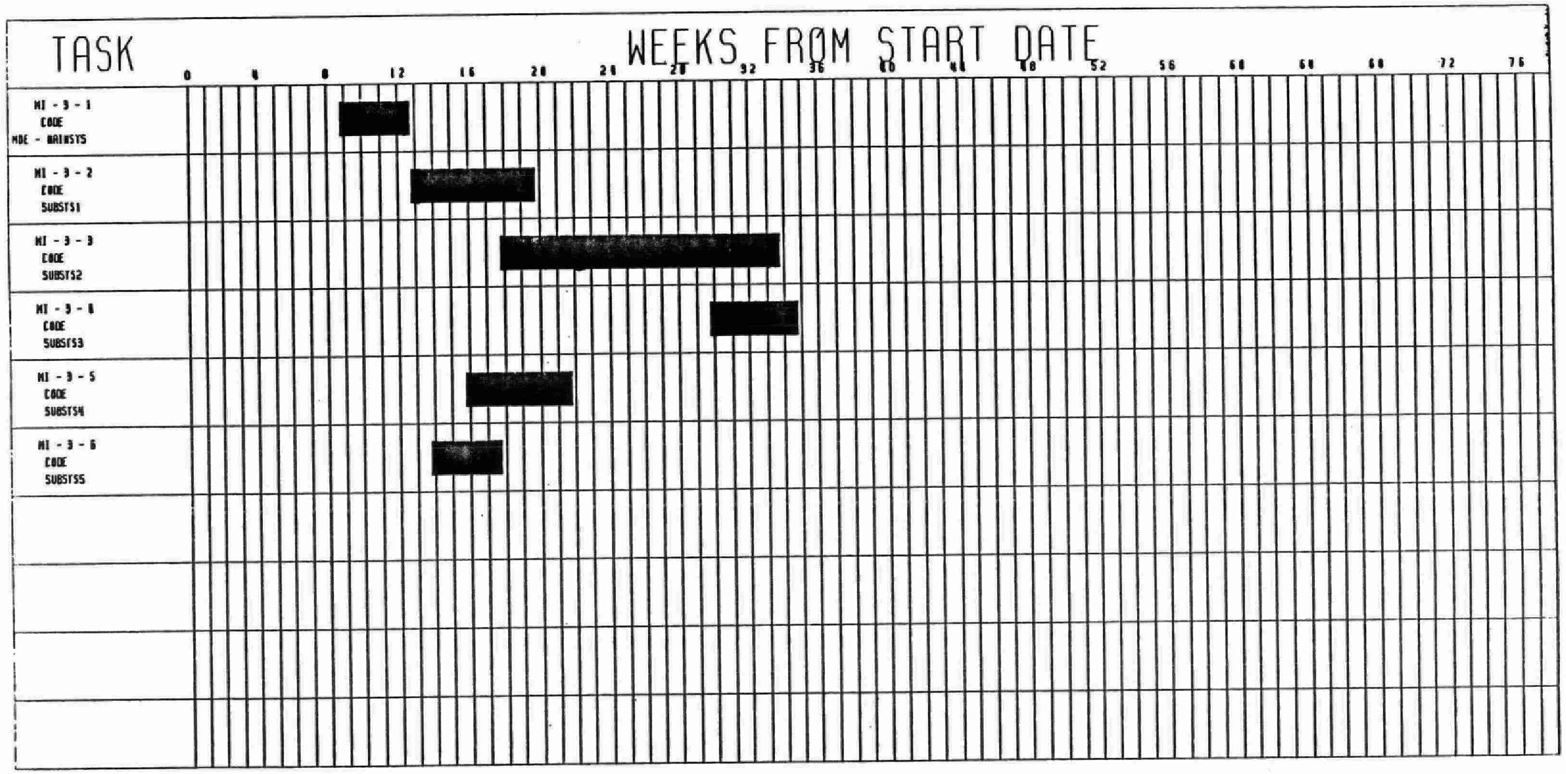
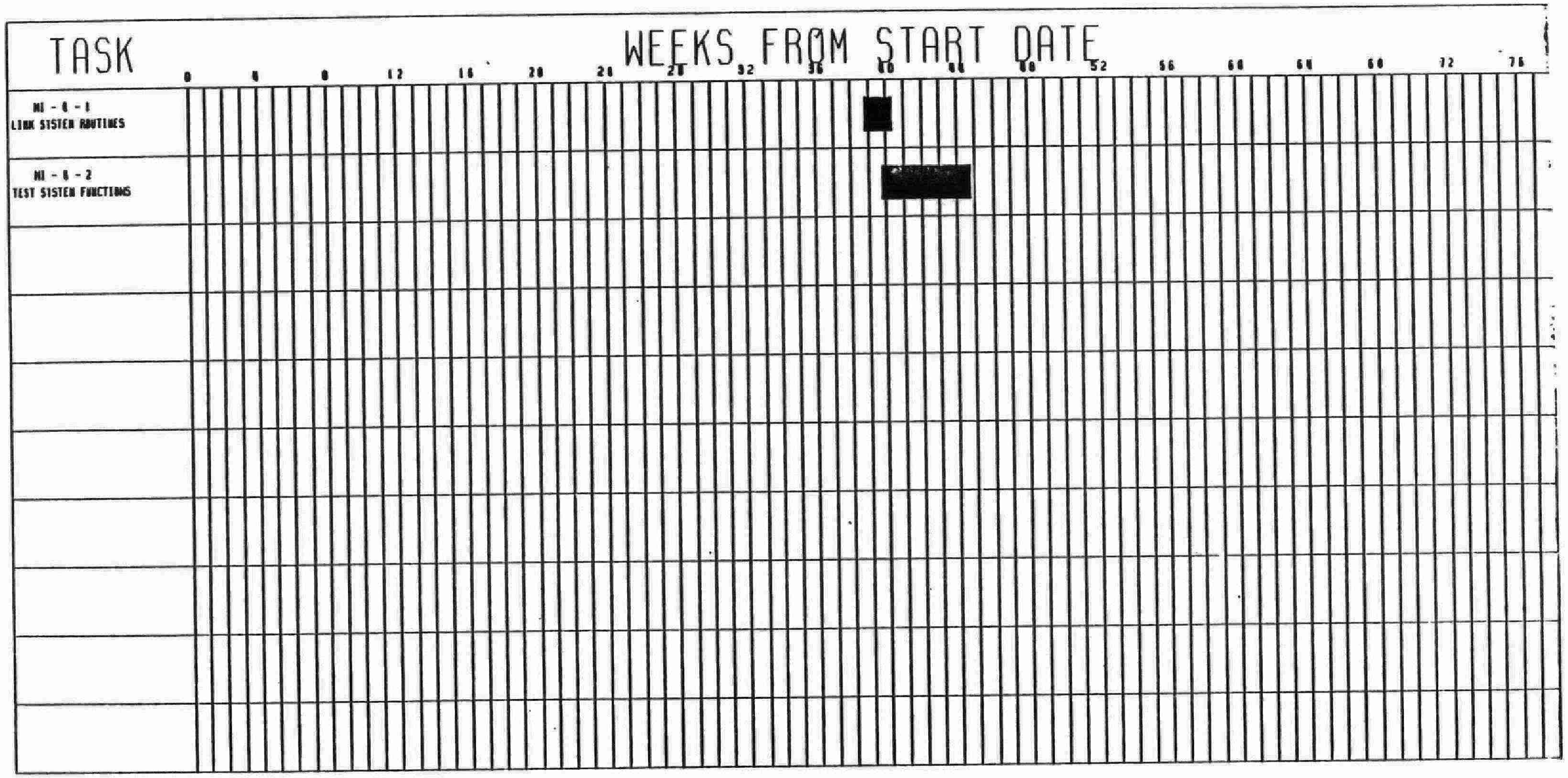
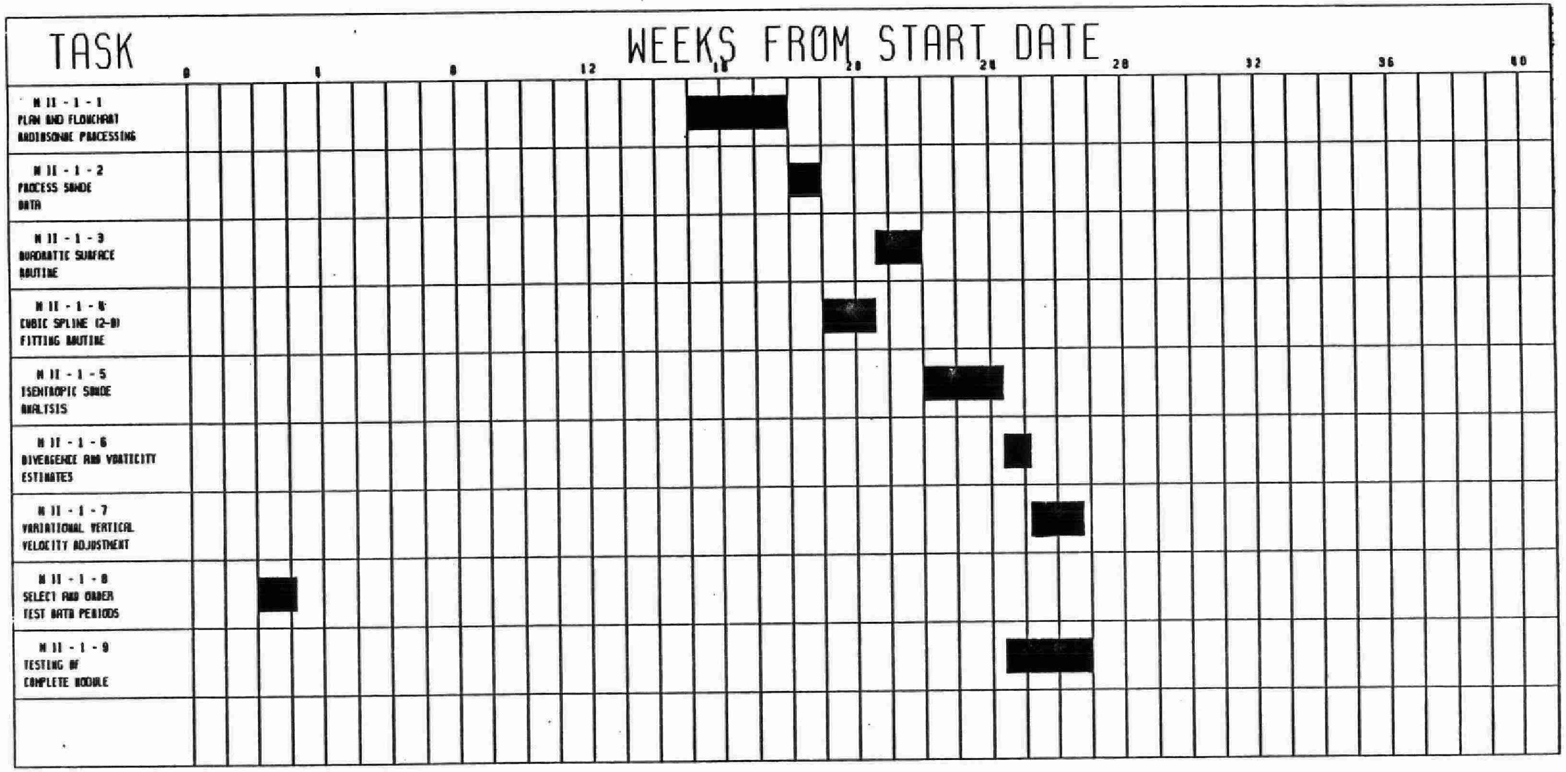
24
28
32
36
40
44
48
52
56
60
64
68
72
76
MI - 1 - 1
FINALIZE DESIGN
CONSTRAINTS
MI - 1 - 2
DEFINE SYSTEM CONFIG.
OF TARGET SYSTEM
MI - 1 - 3
SET UP CODING
SPECIFICATIONS
MI - 1 - 4
DETAIL SUBSYSTEMS AND
OVERALL SYSTEM STRUCTURE


TASK
WEEKS FROM START DATE
12
16
20
32
52
56
72
HI - 2 - 1
PRODUCE DETAILED FLOWCHARTS OF INDIVIDUAL PROCEDURES
HI - 2 - 2
FINALIZE COMMON SET OF INPUT / OUTPUT REQUIREMENTS
HI - 2 - 3
STANDARDIZE FILE STRUCTURE AND NAMING CONVENTIONS


TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76
MI - 3 - 1
CODE
MDE - MAINSYS
MI - 3 - 2
CODE
SUBSYS1
MI - 3 - 3
CODE
SUBSYS2
MI - 3 - 4
CODE
SUBSYS3
MI - 3 - 5
CODE
SUBSYS4
MI - 3 - 6
CODE
SUBSYS5


TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76
MI - 6 - 1
LINK SYSTEM ROUTINES
MI - 6 - 2
TEST SYSTEM FUNCTIONS



TASK
WEEKS FROM START DATE
0
4
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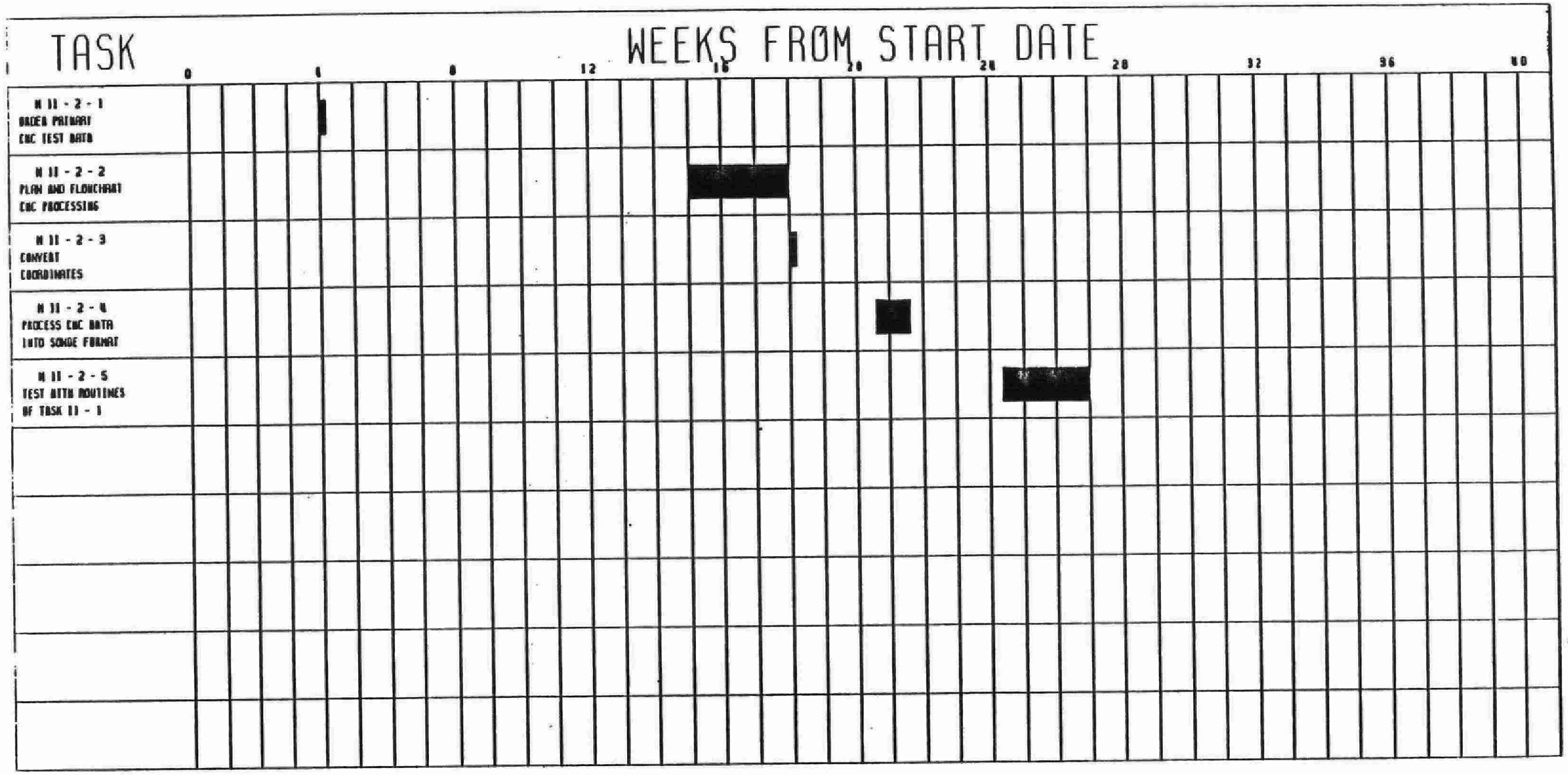
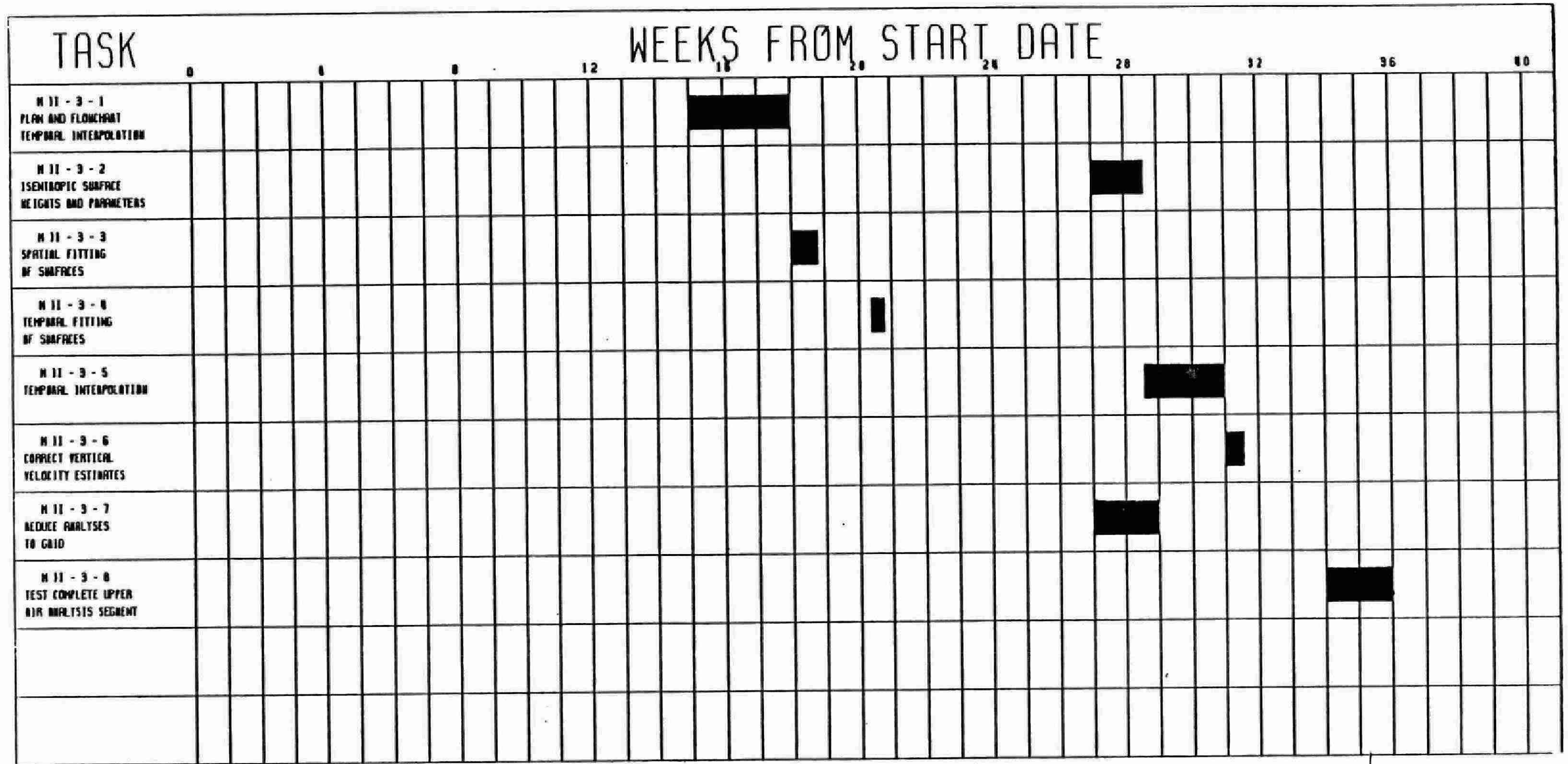
16
20
24
28
32
36
40
M II - 1 - 1
PLAN AND FLOWCHART
RADIOSONDE PROCESSING
M II - 1 - 2
PROCESS SONDE
DATA
M II - 1 - 3
QUADRATIC SURFACE
ROUTINE
M II - 1 - 4
CUBIC SPLINE (2-D)
FITTING ROUTINE
M II - 1 - 5
ISENTROPIC SONDE
ANALYSIS
M II - 1 - 6
DIVERGENCE AND VORTICITY
ESTIMATES
M II - 1 - 7
VARIATIONAL VERTICAL
VELOCITY ADJUSTMENT
M II - 1 - 8
SELECT AND ORDER
TEST DATA PERIODS
M II - 1 - 9
TESTING OF
COMPLETE MODULE


TASK
WEEKS FRØM START DATE
0
4
8
12
16
20
24
28
32
36
40
M II - 2 - 1
ORDER PRIMARY
CMC TEST DATA
M II - 2 - 2
PLAN AND FLOWCHART
CMC PROCESSING
M II - 2 - 3
CONVERT
COORDINATES
M II - 2 - 4
PROCESS CMC DATA
INTO SONDE FORMAT
M II - 2 - 5
TEST WITH ROUTINES
OF TASK II - 1


TASK
WEEKS FROM START DATE
0
4
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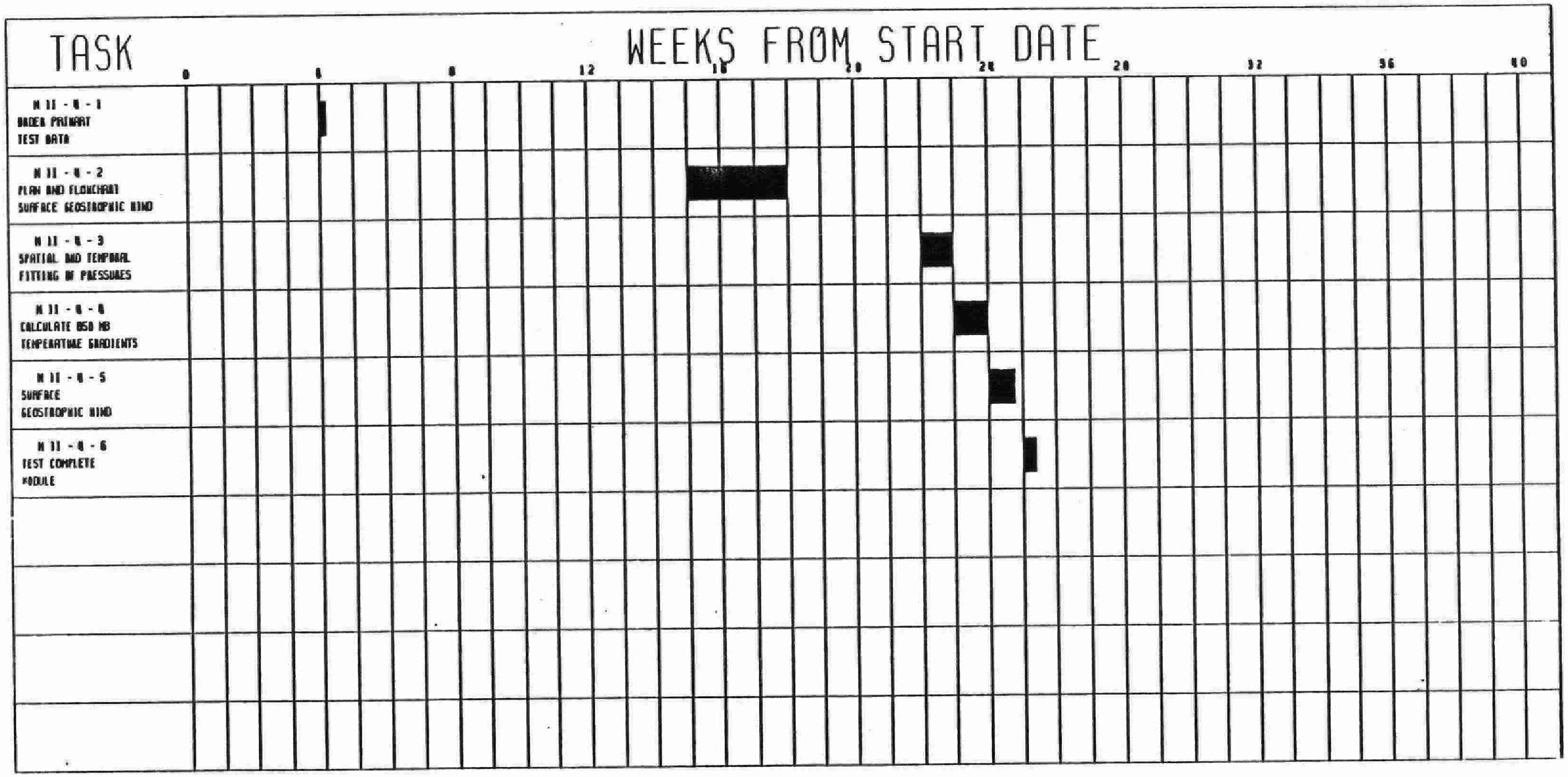
16
20
24
28
32
36
40
M II - 3 - 1
PLAN AND FLOWCHART
TEMPORAL INTERPOLATION
M II - 3 - 2
ISENTROPIC SURFACE
HEIGHTS AND PARAMETERS
M II - 3 - 3
SPATIAL FITTING
OF SURFACES
M II - 3 - 4
TEMPORAL FITTING
OF SURFACES
M II - 3 - 5
TEMPORAL INTERPOLATION
M II - 3 - 6
CORRECT VERTICAL
VELOCITY ESTIMATES
M II - 3 - 7
REDUCE ANALYSES
TO GRID
M II - 3 - 8
TEST COMPLETE UPPER
AIR ANALYSIS SEGMENT


TASK
WEEKS FROM START DATE
0
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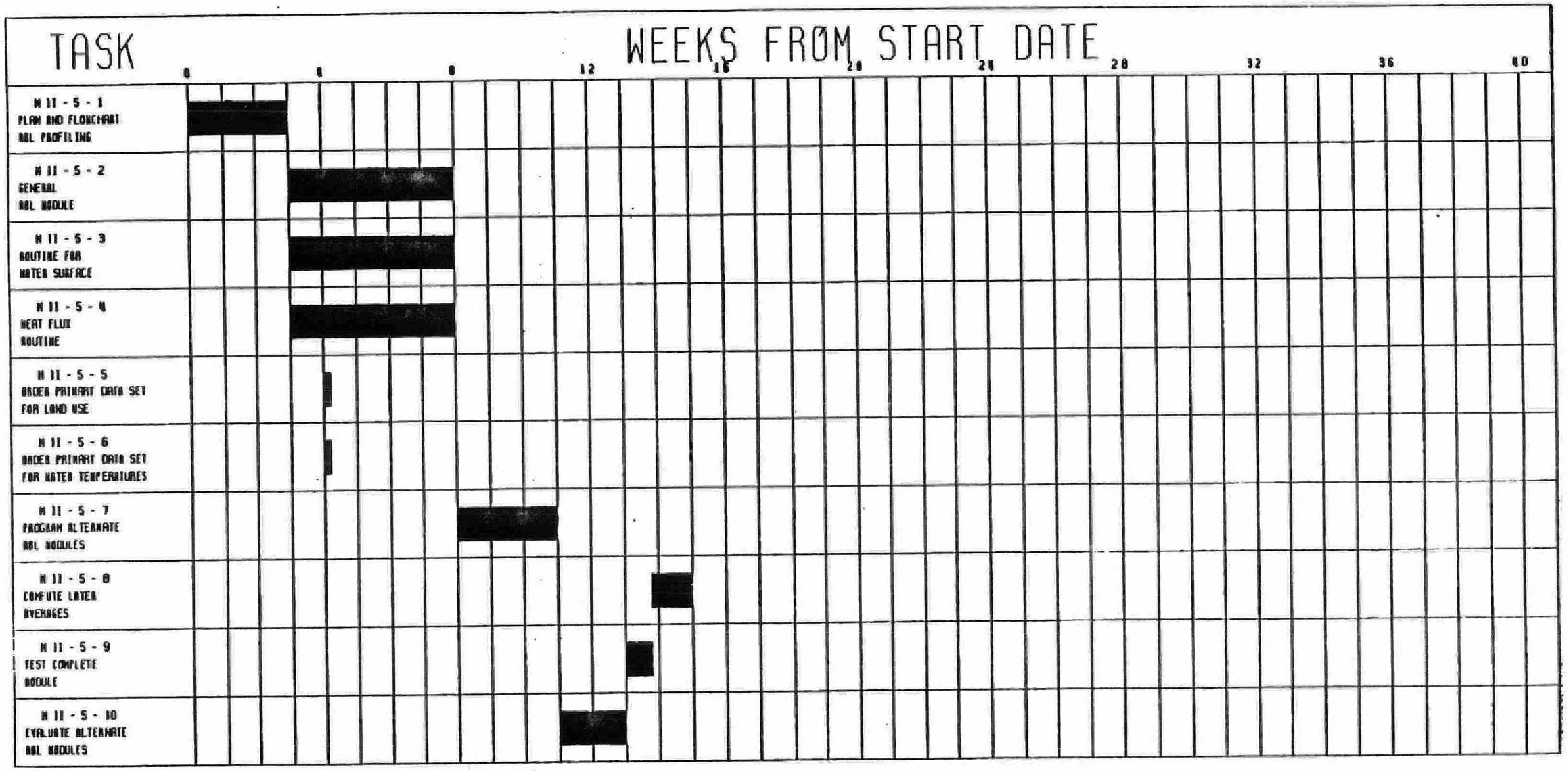
12
16
20
24
28
32
36
40
M 11 - 4 - 1
ORDER PRIMARY
TEST DATA
M 11 - 4 - 2
PLAN AND FLOWCHART
SURFACE GEOSTROPHIC WIND
M 11 - 4 - 3
SPATIAL AND TEMPORAL
FITTING OF PRESSURES
M 11 - 4 - 4
CALCULATE 850 MB
TEMPERATURE GRADIENTS
M 11 - 4 - 5
SURFACE
GEOSTROPHIC WIND
M 11 - 4 - 6
TEST COMPLETE
MODULE



TASK
WEEKS FROM START DATE
0
4
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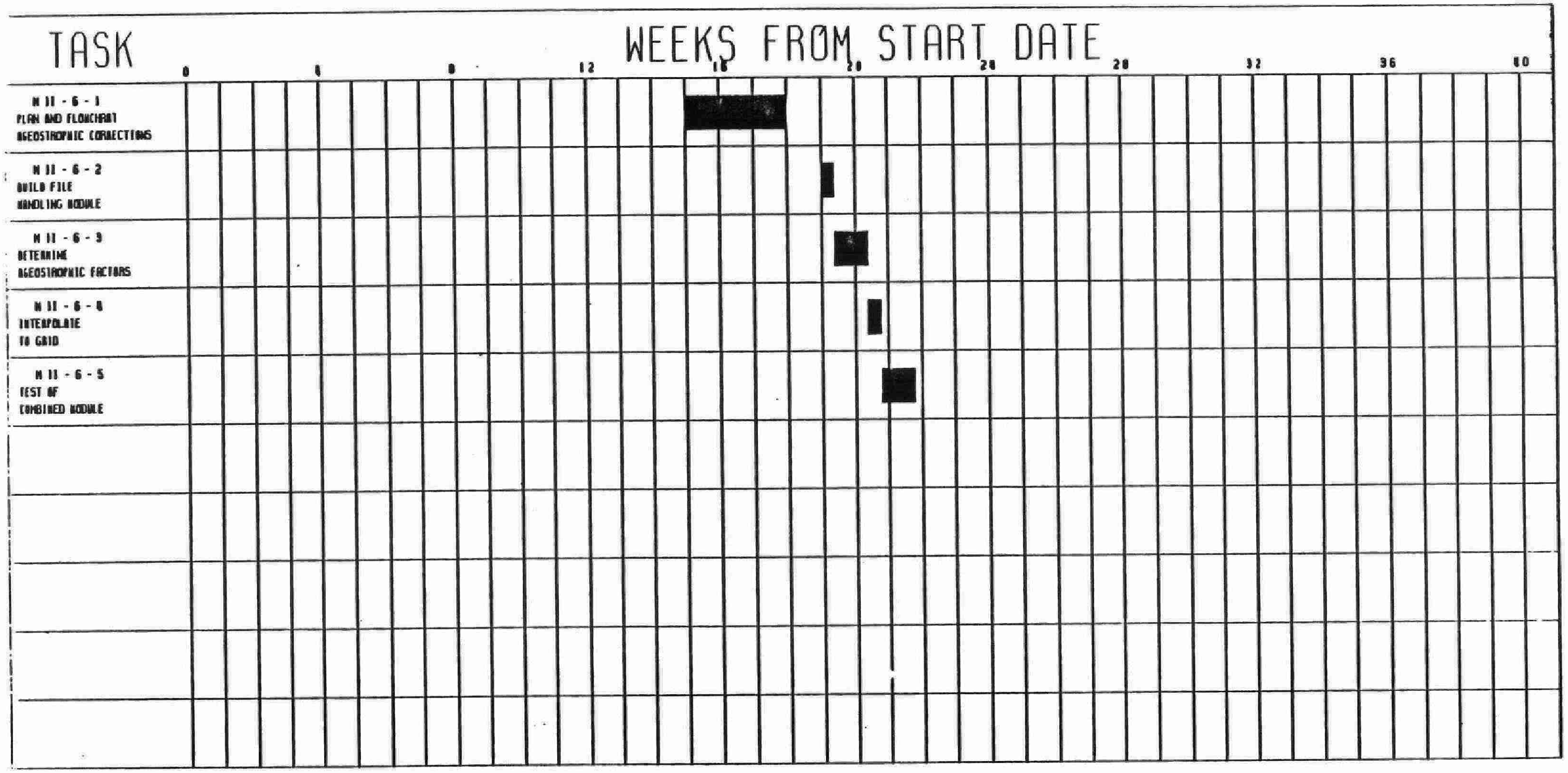
16
20
24
28
32
36
40
M II - 5 - 1
PLAN AND FLOWCHART
ABL PROFILING
M II - 5 - 2
GENERAL
ABL MODULE
M II - 5 - 3
ROUTINE FOR
WATER SURFACE
M II - 5 - 4
HEAT FLUX
ROUTINE
M II - 5 - 5
ORDER PRIMARY DATA SET
FOR LAND USE
M II - 5 - 6
ORDER PRIMARY DATA SET
FOR WATER TEMPERATURES
M II - 5 - 7
PROGRAM ALTERNATE
ABL MODULES
M II - 5 - 8
COMPUTE LATER
AVERAGES
M II - 5 - 9
TEST COMPLETE
MODULE
M II - 5 - 10
EVALUATE ALTERNATE
ABL MODULES


TASK
WEEKS FROM START DATE
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4
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24
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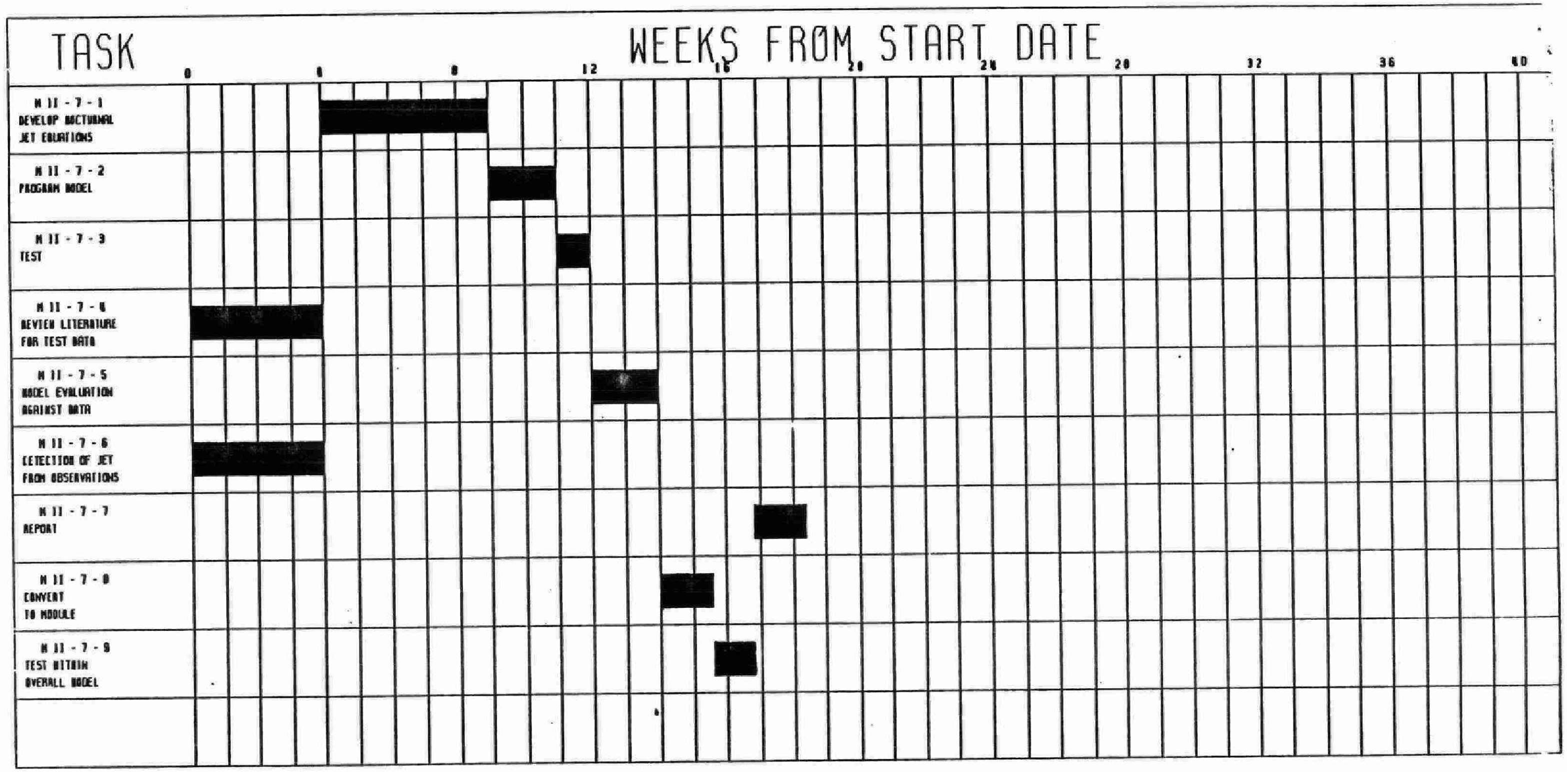
32
36
40
M II - 6 - 1
PLAN AND FLOWCHART
AGEOSTROPHIC CORRECTIONS
M II - 6 - 2
BUILD FILE
HANDLING MODULE
M II - 6 - 3
DETERMINE
AGEOSTROPHIC FACTORS
M II - 6 - 4
INTERPOLATE
TO GRID
M II - 6 - 5
TEST OF
COMBINED MODULE


TASK
WEEKS FROM START DATE
0
4
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16
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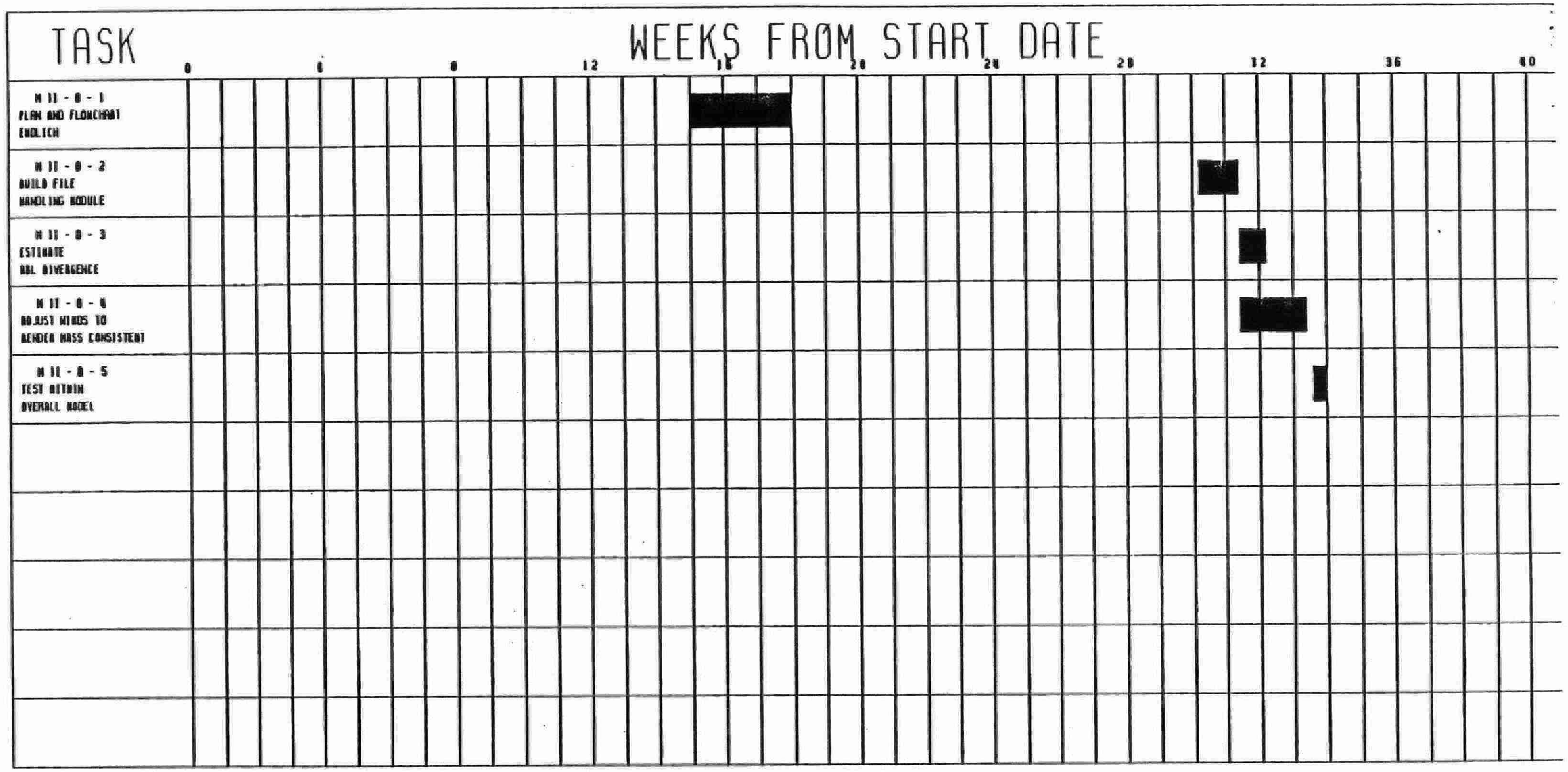
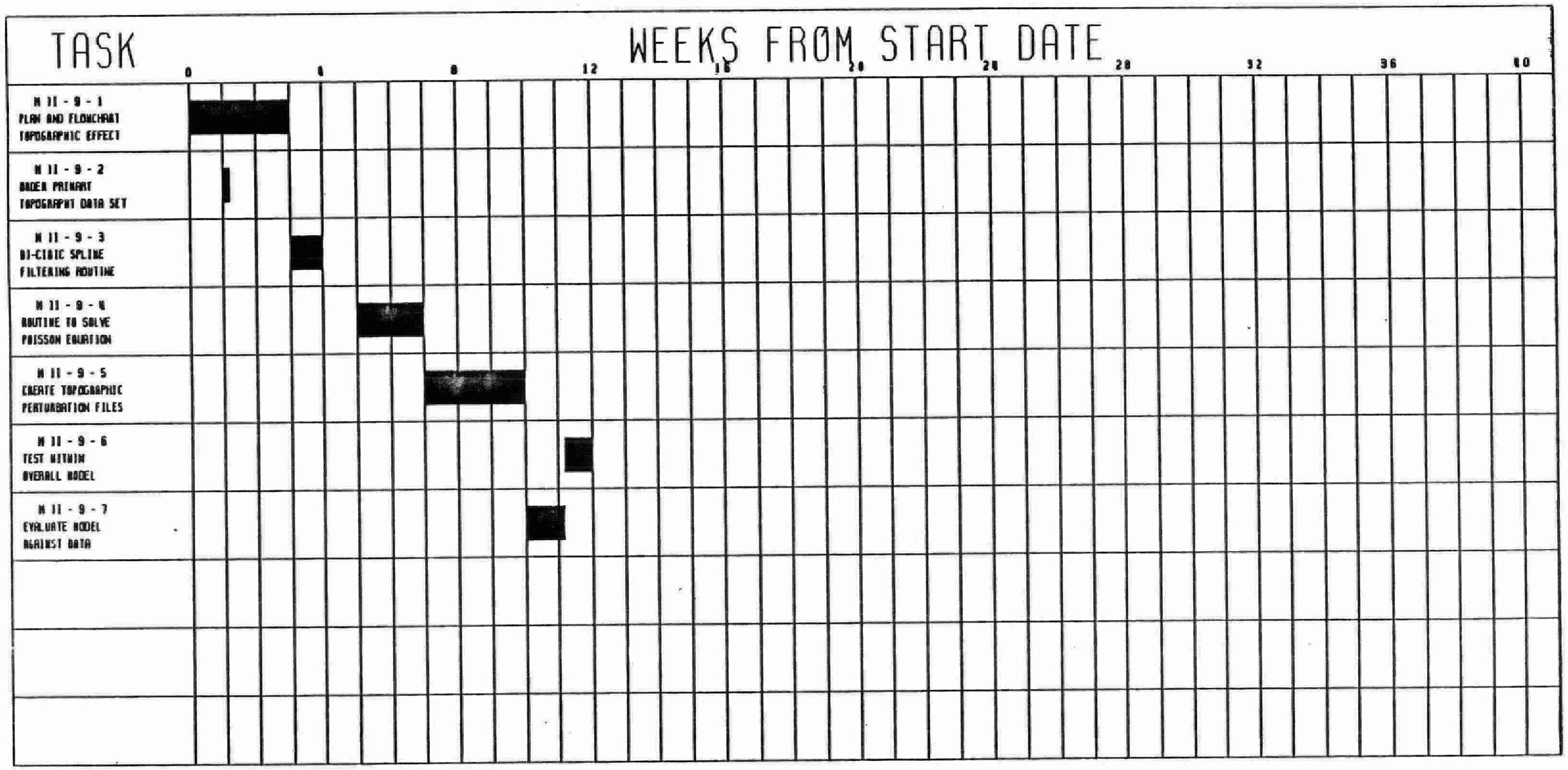
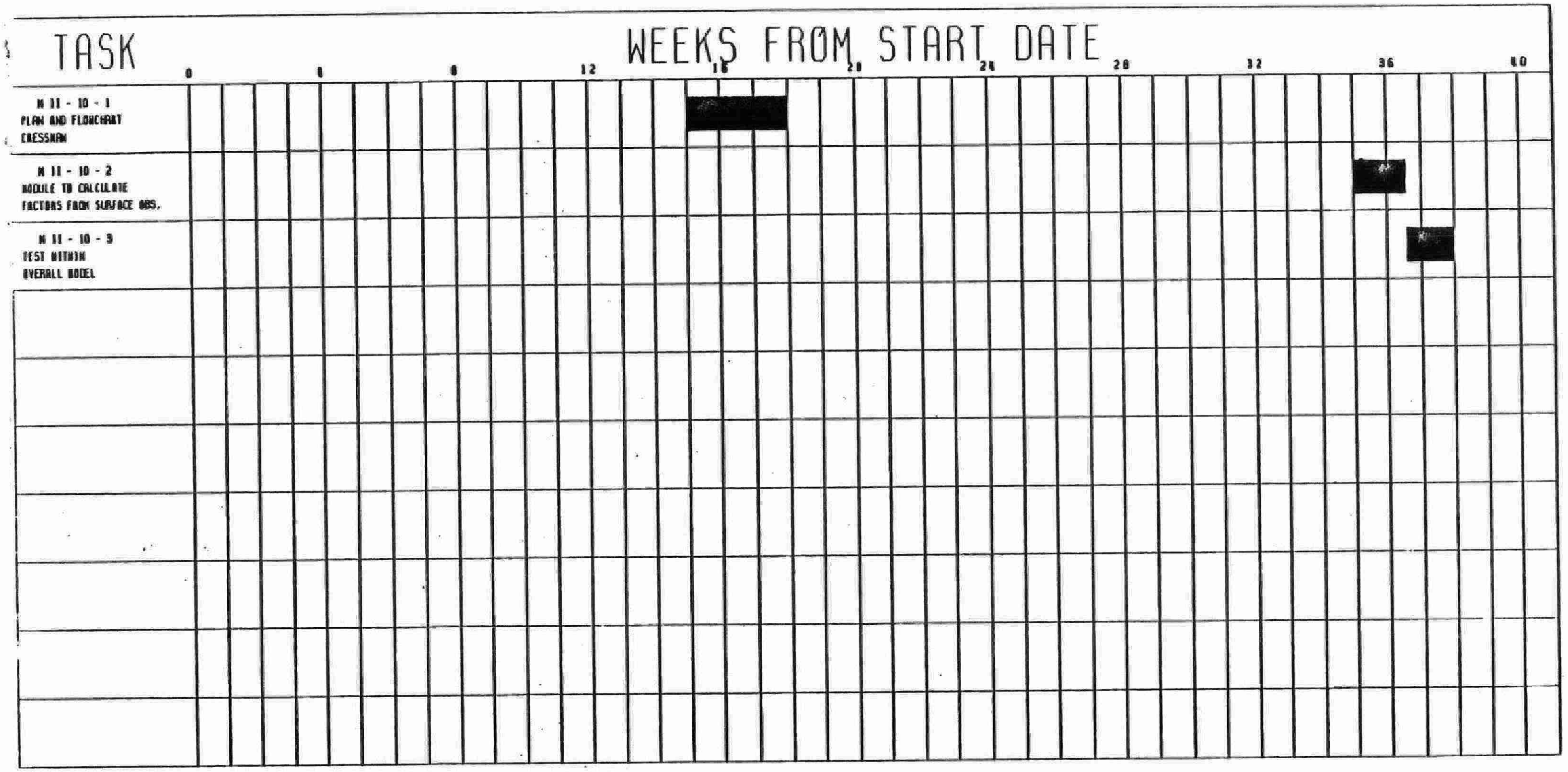
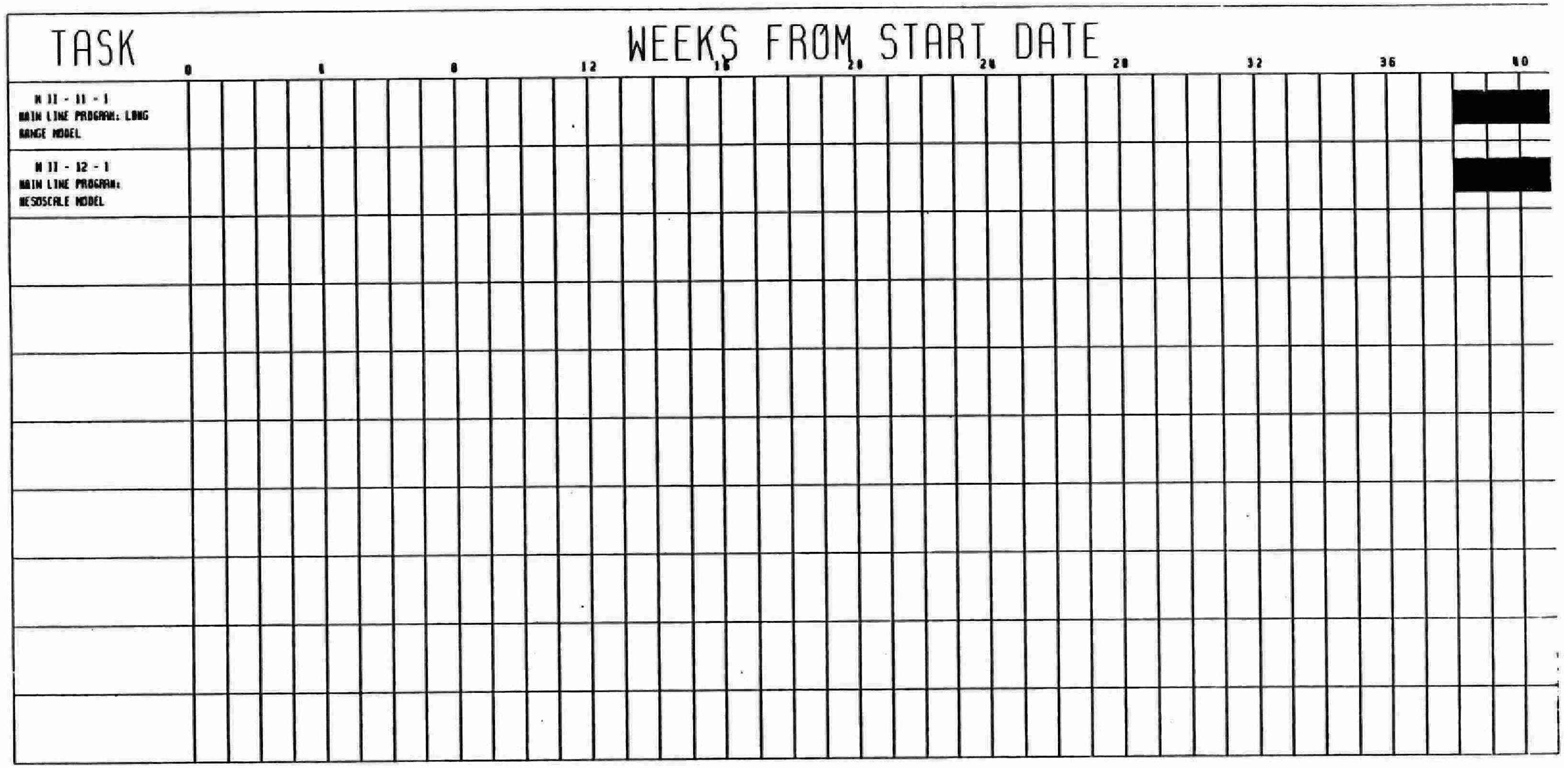
24
28
32
36
40
N II - 7 - 1
DEVELOP NOCTURNAL
JET EQUATIONS
N II - 7 - 2
PROGRAM MODEL
N II - 7 - 3
TEST
N II - 7 - 4
REVIEW LITERATURE
FOR TEST DATA
N II - 7 - 5
MODEL EVALUATION
AGAINST DATA
N II - 7 - 6
DETECTION OF JET
FROM OBSERVATIONS
N II - 7 - 7
REPORT
N II - 7 - 8
CONVERT
TO MODULE
N II - 7 - 9
TEST WITHIN
OVERALL MODEL


TASK
WEEKS FROM START DATE
0
4
8
12
16
20
24
28
32
36
40
M II - B - 1
PLAN AND FLOWCHART
ENGLICH
M II - B - 2
BUILD FILE
HANDLING MODULE
M II - B - 3
ESTIMATE
ABL DIVERGENCE
M II - B - 4
ADJUST WINDS TO
RENDER MASS CONSISTENT
M II - B - 5
TEST WITHIN
OVERALL MODEL



TASK
WEEKS FROM START DATE
0
4
8
12
16
20
24
28
32
36
40
M II - 9 - 1
PLAN AND FLOWCHART
TOPOGRAPHIC EFFECT
M II - 9 - 2
ORDER PRIMARY
TOPOGRAPHY DATA SET
M II - 9 - 3
BI-CUBIC SPLINE
FILTERING ROUTINE
M II - 9 - 4
ROUTINE TO SOLVE
POISSON EQUATION
M II - 9 - 5
CREATE TOPOGRAPHIC
PERTURBATION FILES
M II - 9 - 6
TEST WITHIN
OVERALL MODEL
M II - 9 - 7
EVALUATE MODEL
AGAINST DATA


TASK
WEEKS FROM START DATE
0
12
28
32
36
40
M 11 - 10 - 1
PLAN AND FLOWCHART
CRESSMAN
M 11 - 10 - 2
MODULE TO CALCULATE
FACTORS FROM SURFACE OBS.
M 11 - 10 - 3
TEST WITHIN
OVERALL MODEL


TASK
WEEKS FROM START DATE
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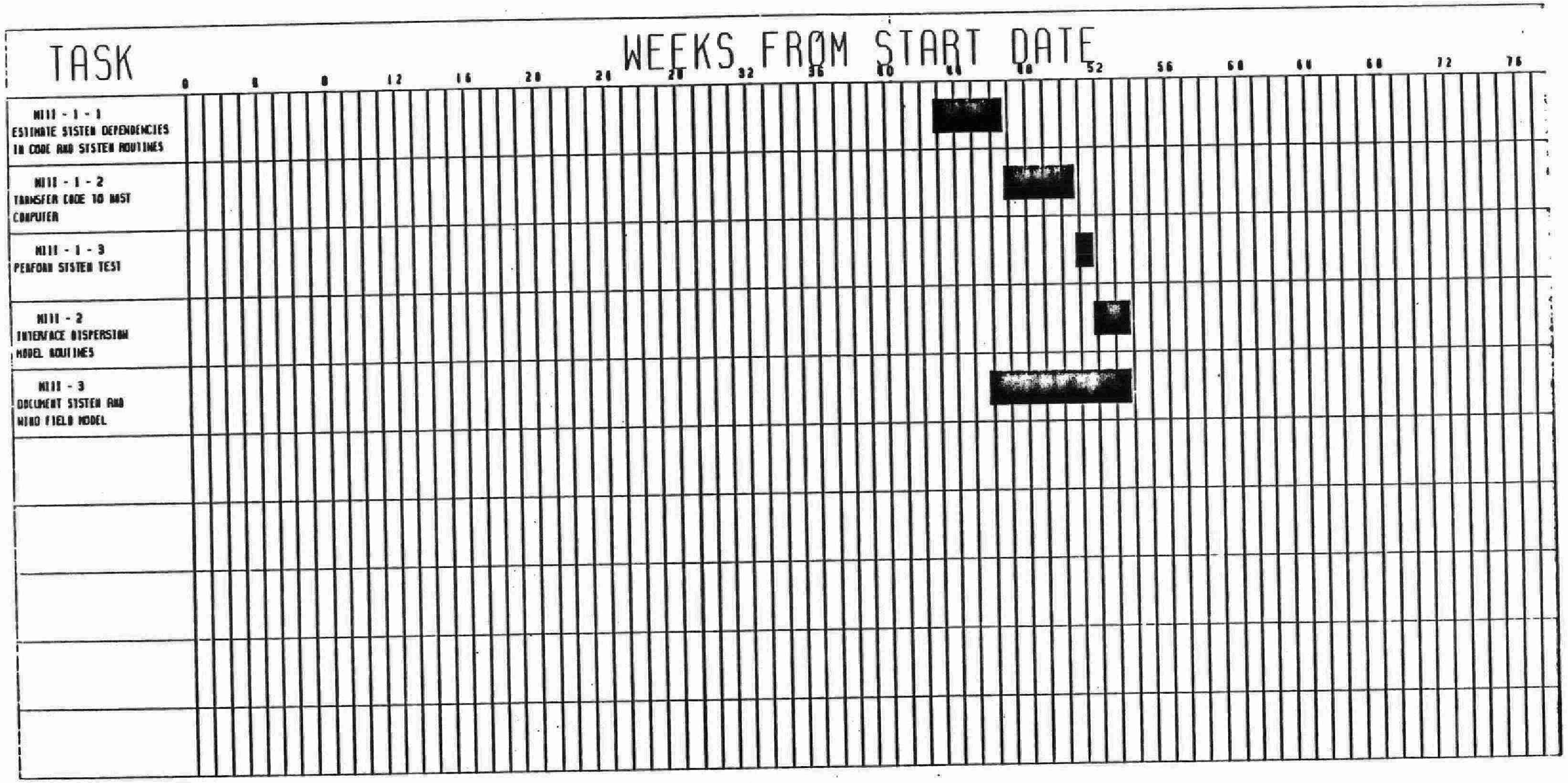
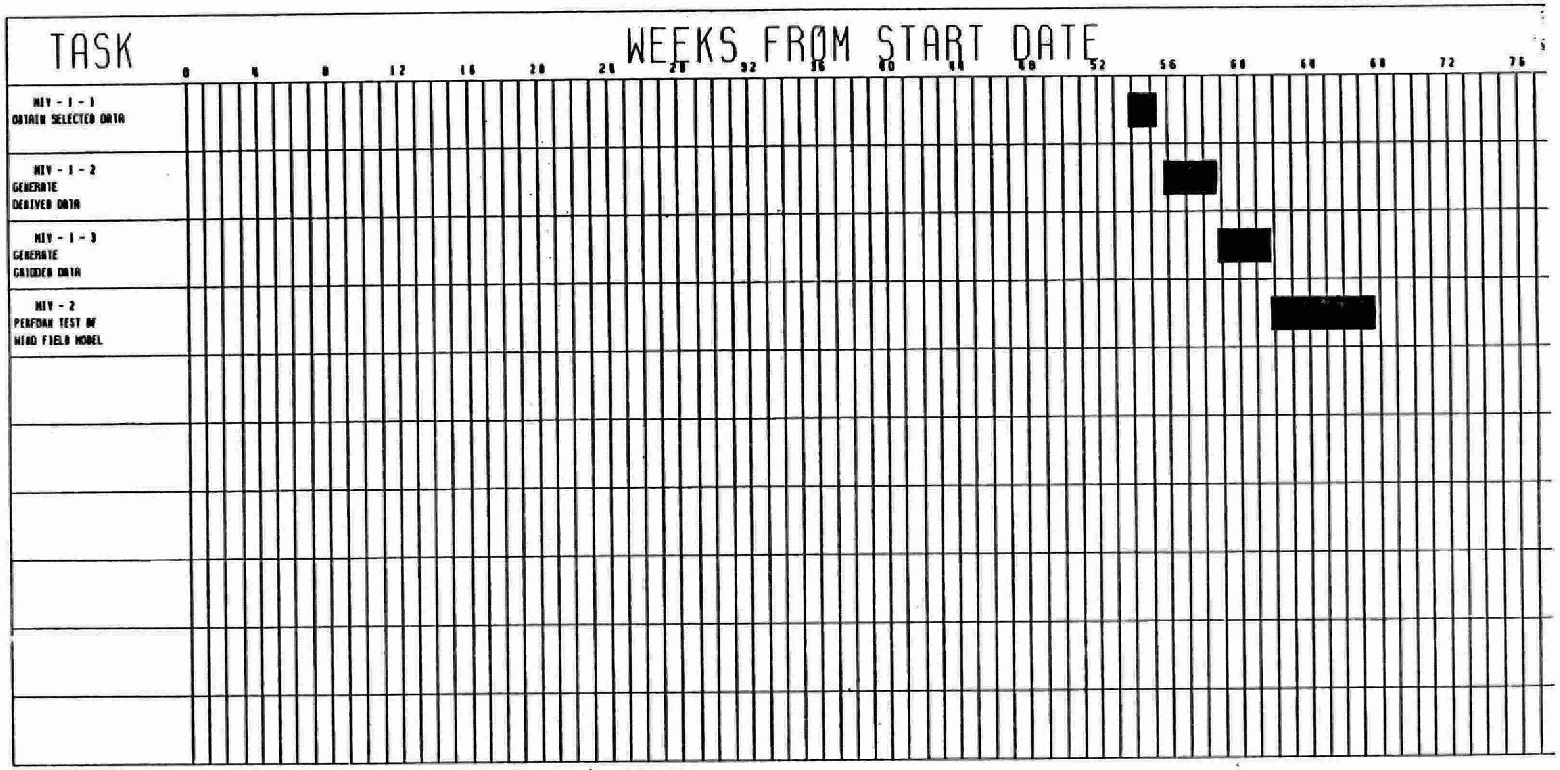
M II - 11 - 1
MAIN LINE PROGRAM: LONG RANGE MODEL
M II - 12 - 1
MAIN LINE PROGRAM: MESOSCALE MODEL


TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76
MIII - 1 - 1
ESTIMATE SYSTEM DEPENDENCIES IN CODE AND SYSTEM ROUTINES
MIII - 1 - 2
TRANSFER CODE TO HOST COMPUTER
MIII - 1 - 3
PERFORM SYSTEM TEST
MIII - 2
INTERFACE DISPERSION MODEL ROUTINES
MIII - 3
DOCUMENT SYSTEM AND WIND FIELD MODEL



TASK
WEEKS FRØM START DATE
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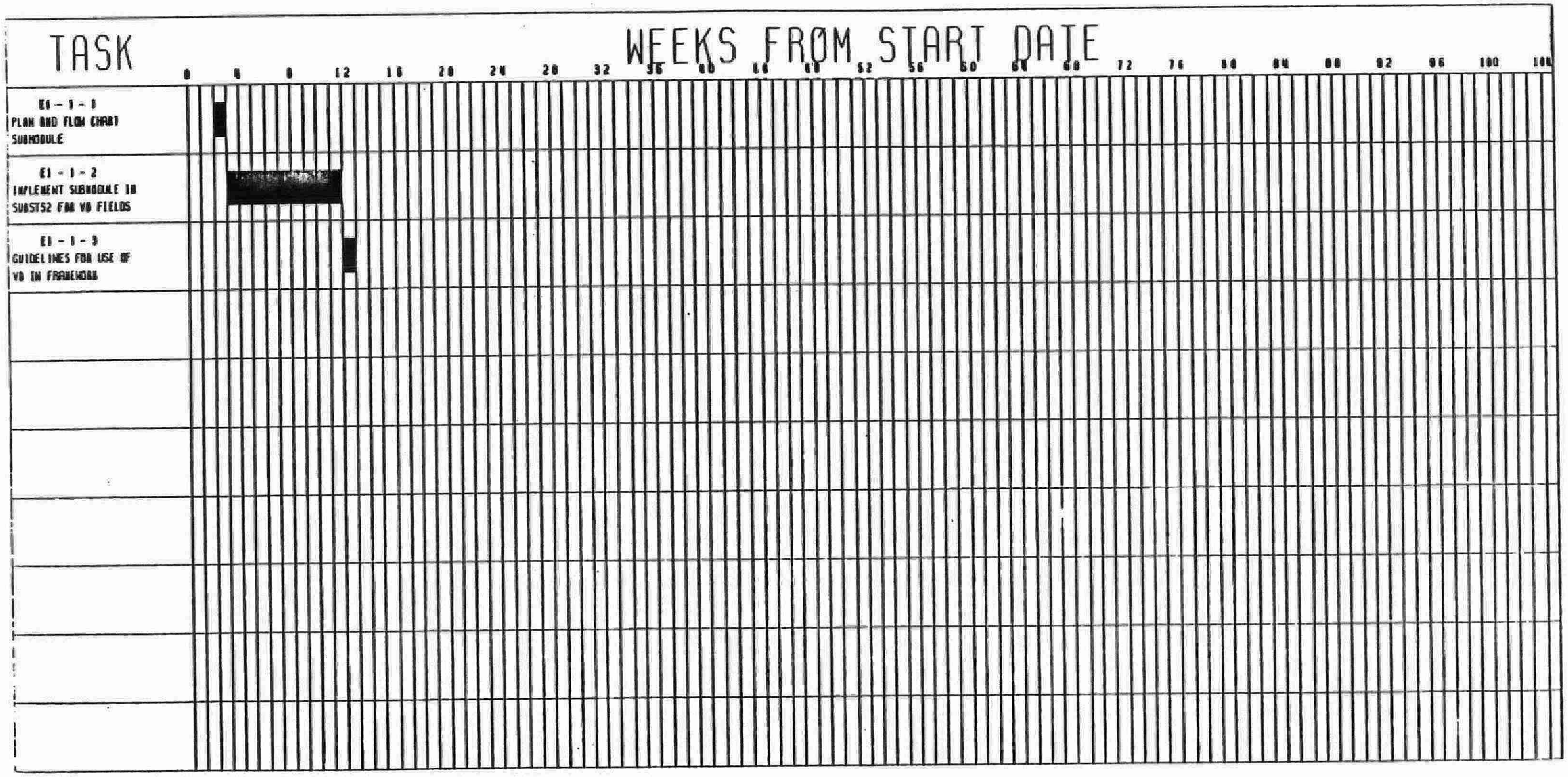
36
40
44
48
52
56
60
64
68
72
76
MIV - I - 1
OBTAIN SELECTED DATA
MIV - I - 2
GENERATE
DERIVED DATA
MIV - I - 3
GENERATE
GRIDDED DATA
MIV - 2
PERFORM TEST OF
WIND FIELD MODEL


TASK
WEEKS FROM START DATE
0
4
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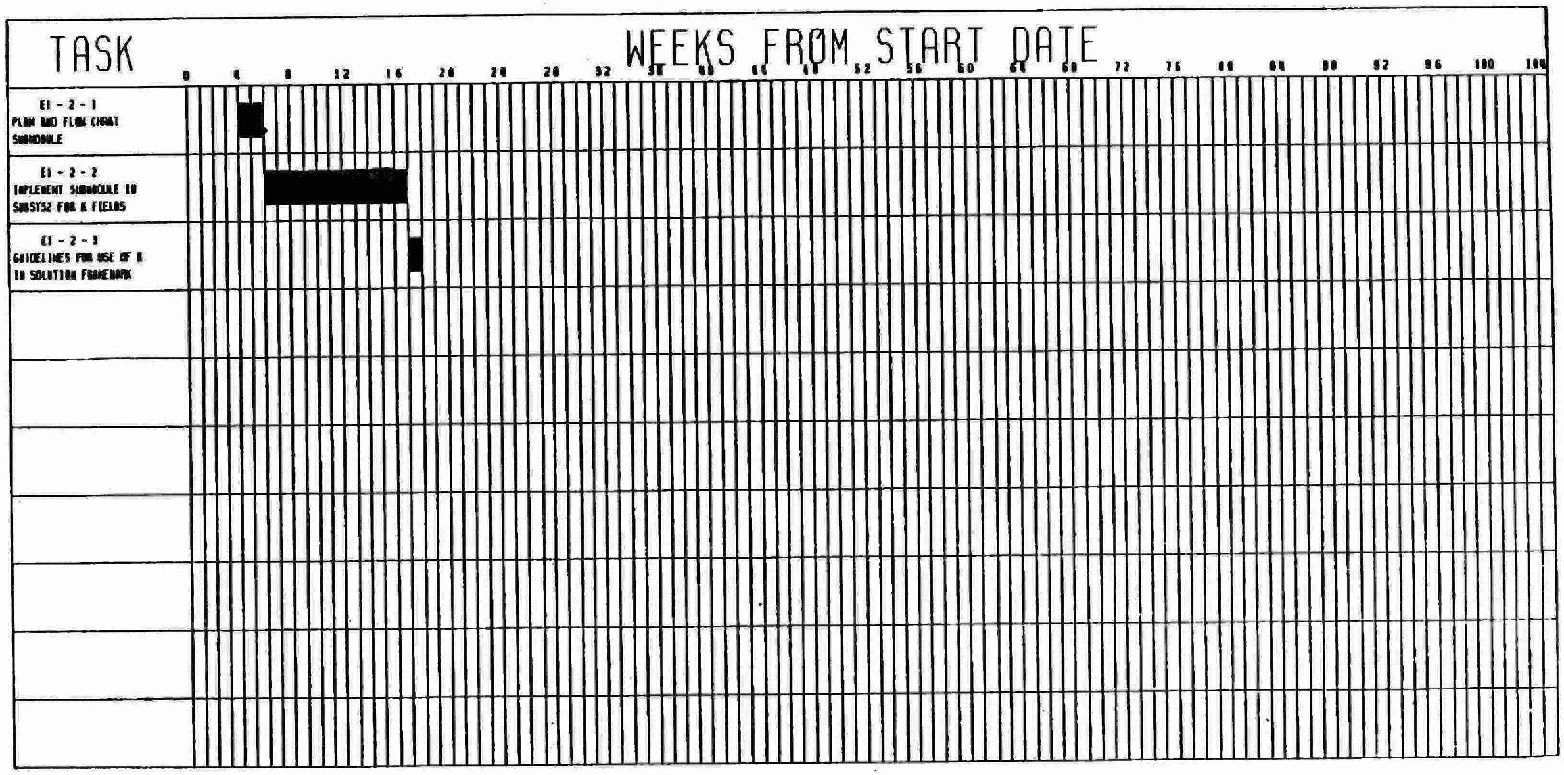
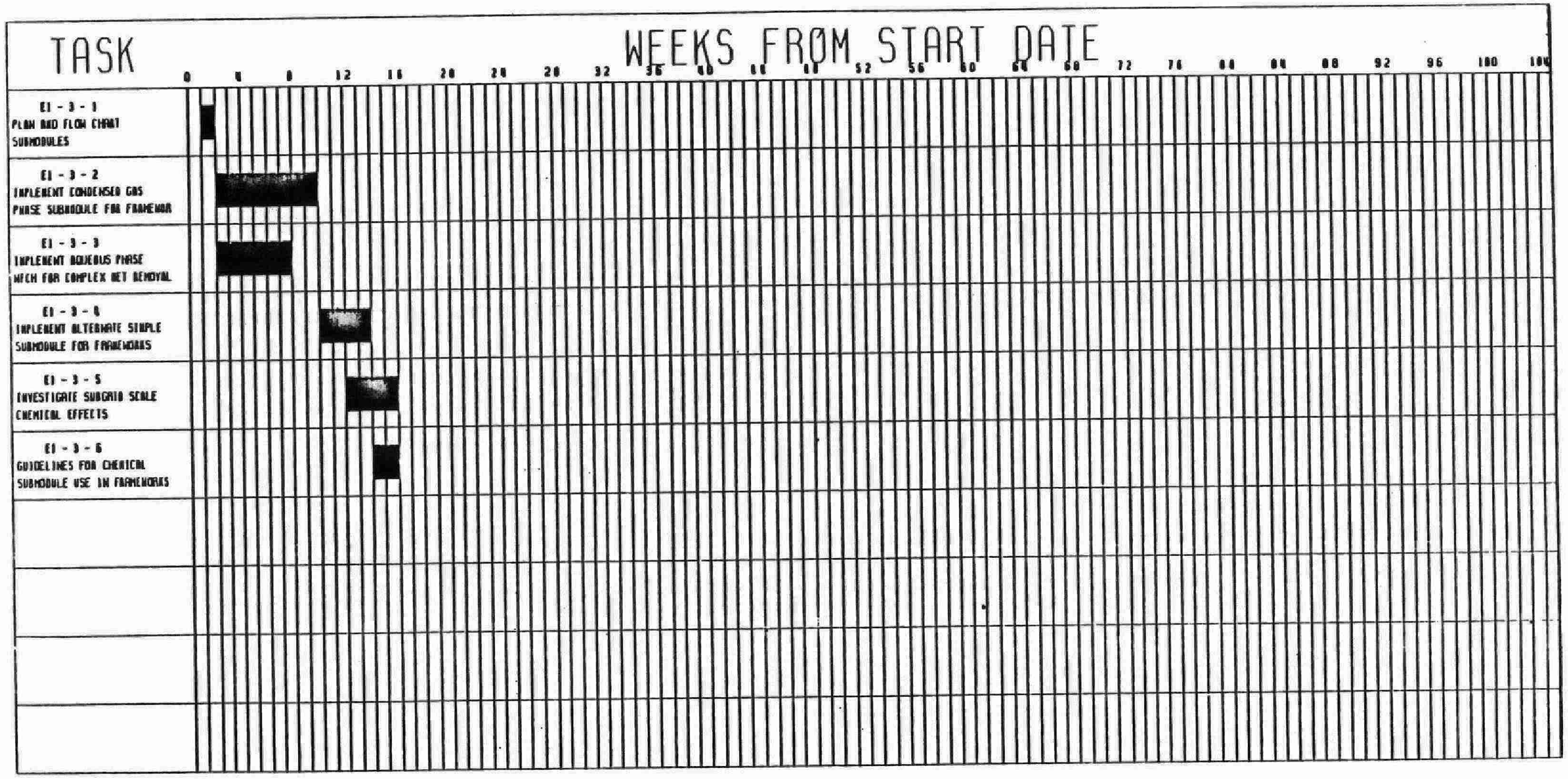
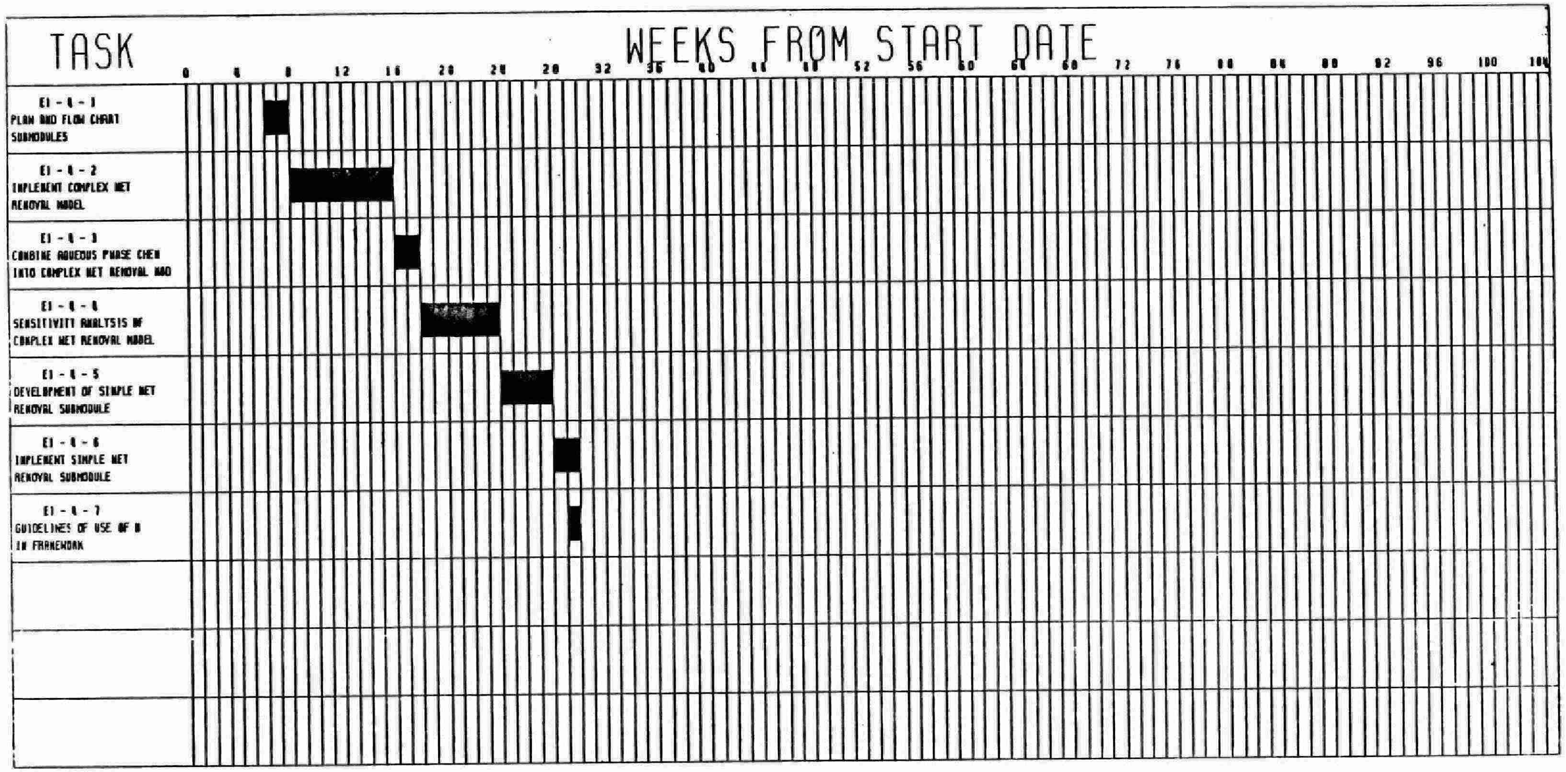
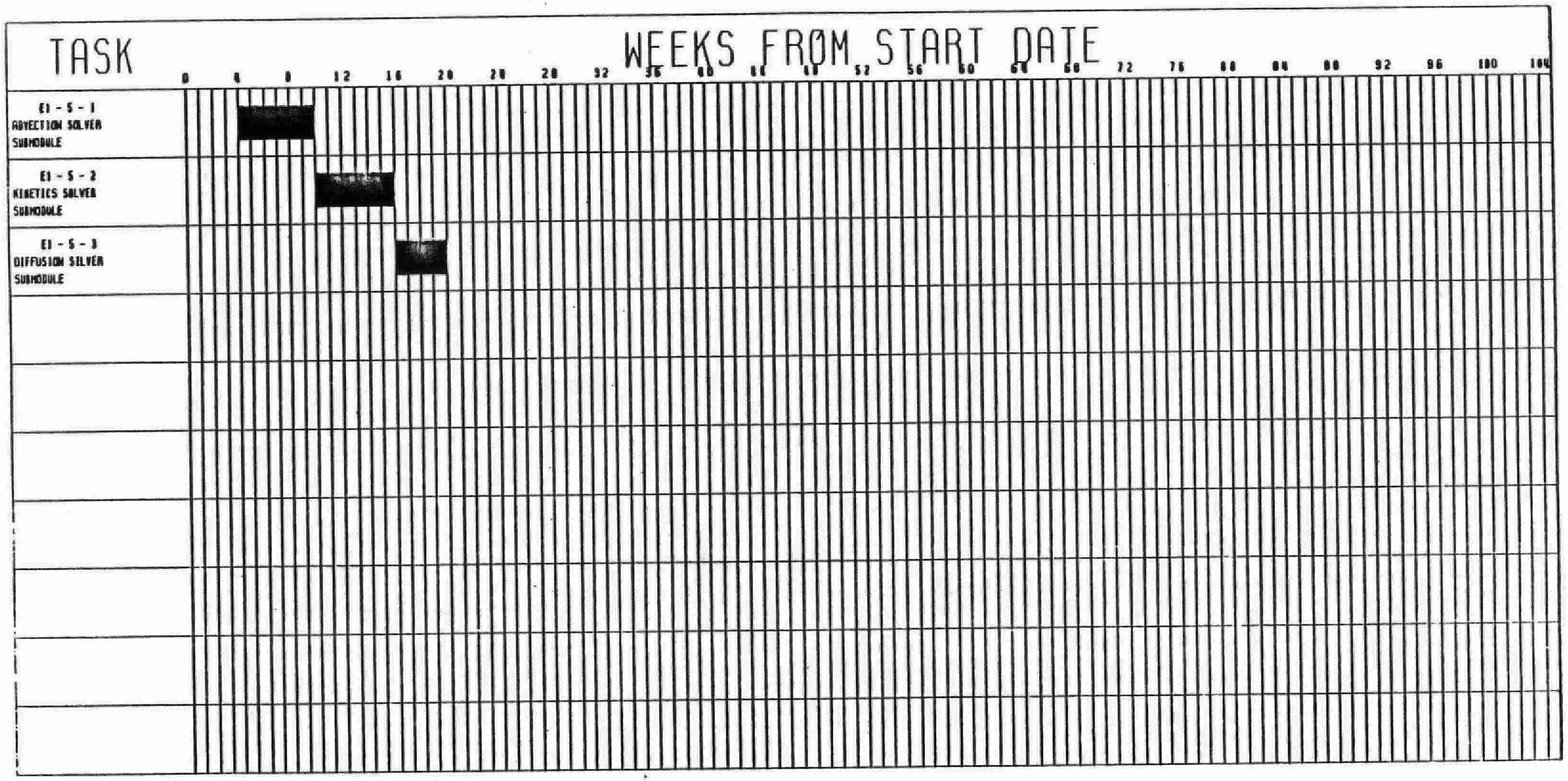
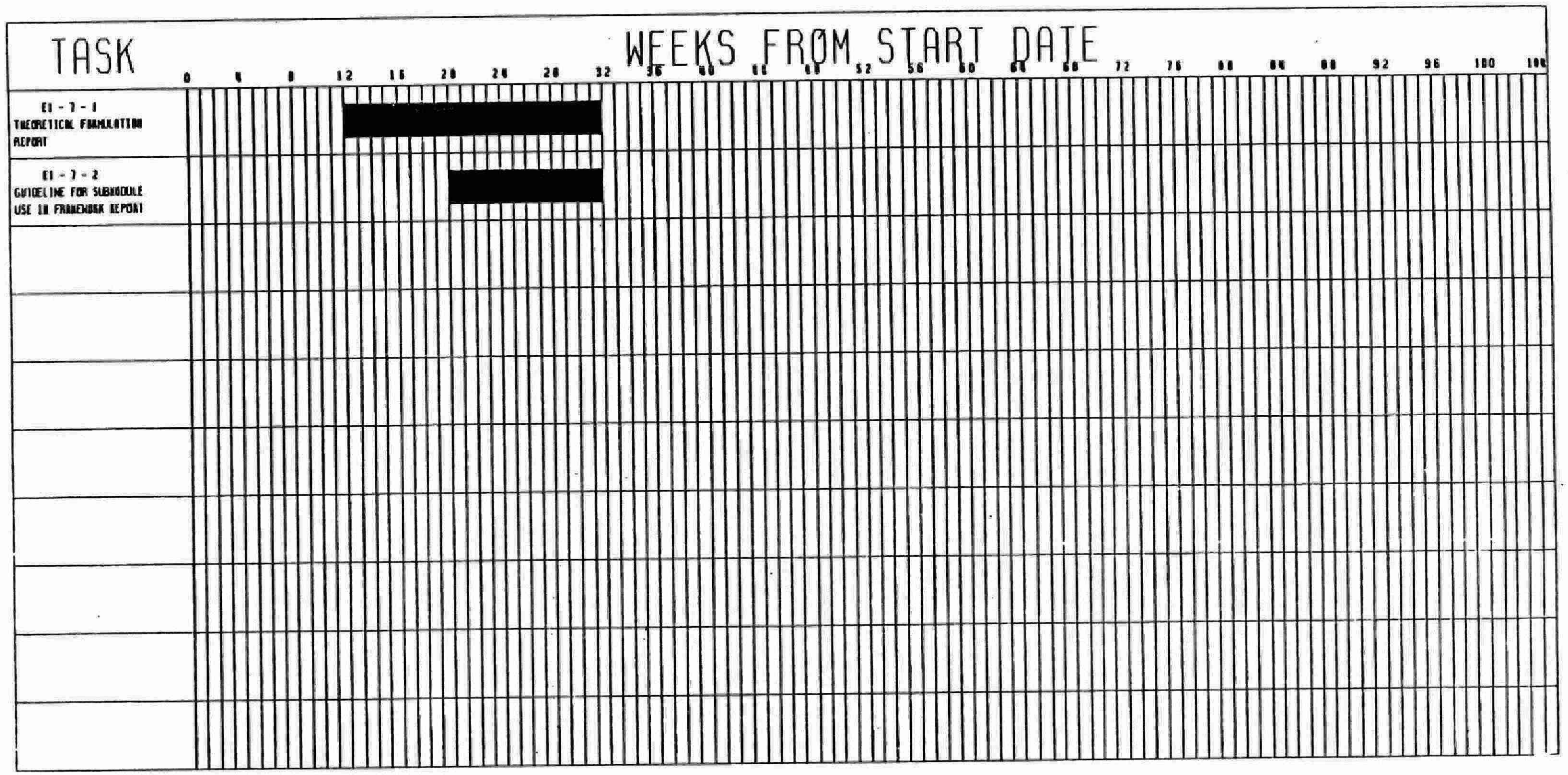
24
28
32
36
40
44
48
52
56
60
64
68
72
76
80
84
88
92
96
100
E1 - 1 - 1
PLAN AND FLOW CHART SUBMODULE
E1 - 1 - 2
IMPLEMENT SUBMODULE IN SUBST52 FOR VD FIELDS
E1 - 1 - 3
GUIDELINES FOR USE OF VD IN FRAMEWORK


TASK
WEEKS FROM START DATE
EI - 2 - 1
PLAN AND FLOW CHART SUBMODULE
EI - 2 - 2
IMPLEMENT SUBMODULE IN SUBSYS2 FOR K FIELDS
EI - 2 - 3
GUIDELINES FOR USE OF K IN SOLUTION FRAMEWORK


TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 104
EI - 3 - 1
PLAN AND FLOW CHART SUBMODULES
EI - 3 - 2
IMPLEMENT CONDENSED GAS PHASE SUBMODULE FOR FRAMEWOR
EI - 3 - 3
IMPLEMENT AQUEOUS PHASE MECH FOR COMPLEX WET REMOVAL
EI - 3 - 4
IMPLEMENT ALTERNATE SIMPLE SUBMODULE FOR FRAMEWORKS
EI - 3 - 5
INVESTIGATE SUBGRID SCALE CHEMICAL EFFECTS
EI - 3 - 6
GUIDELINES FOR CHEMICAL SUBMODULE USE IN FRAMEWORKS


TASK
WEEKS FROM START DATE
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56 60 64 68 72 76 80 84 88 92 96 100 104
E1 - 4 - 1
PLAN AND FLOW CHART SUBMODULES
E1 - 4 - 2
IMPLEMENT COMPLEX WET REMOVAL MODEL
E1 - 4 - 3
COMBINE AQUEOUS PHASE CHEM INTO COMPLEX WET REMOVAL MOD
E1 - 4 - 4
SENSITIVITY ANALYSIS OF COMPLEX WET REMOVAL MODEL
E1 - 4 - 5
DEVELOPMENT OF SIMPLE WET REMOVAL SUBMODULE
E1 - 4 - 6
IMPLEMENT SIMPLE WET REMOVAL SUBMODULE
E1 - 4 - 7
GUIDELINES OF USE OF M IN FRAMEWORK


TASK
WEEKS FROM START DATE
0
12
16
32
52
56
72
76
92
96
100
104
E1 - S - 1
ADVECTION SOLVER
SUBMODULE
E1 - S - 2
KINETICS SOLVER
SUBMODULE
E1 - S - 3
DIFFUSION SOLVER
SUBMODULE


TASK
WEEKS FROM START DATE
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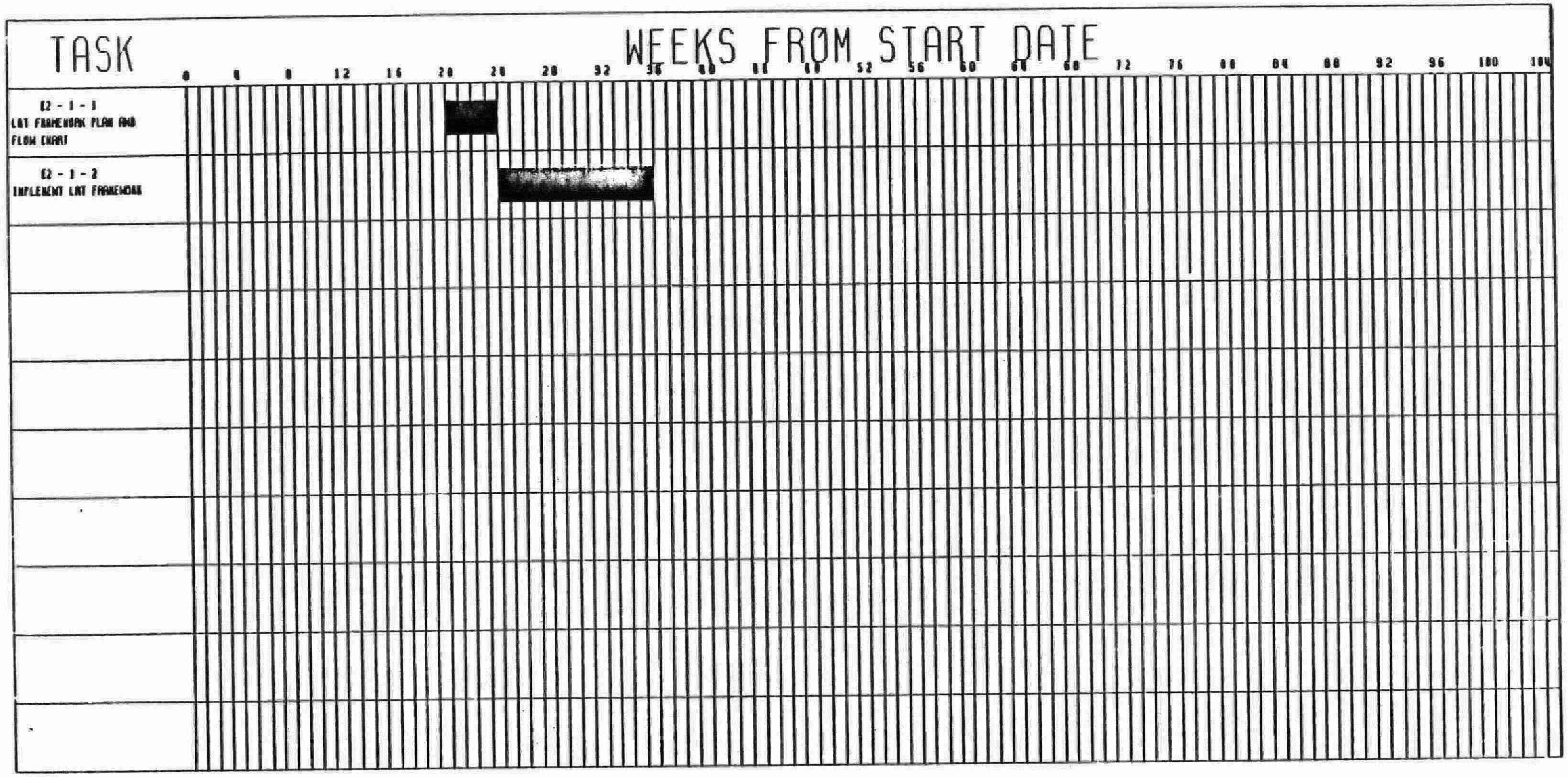
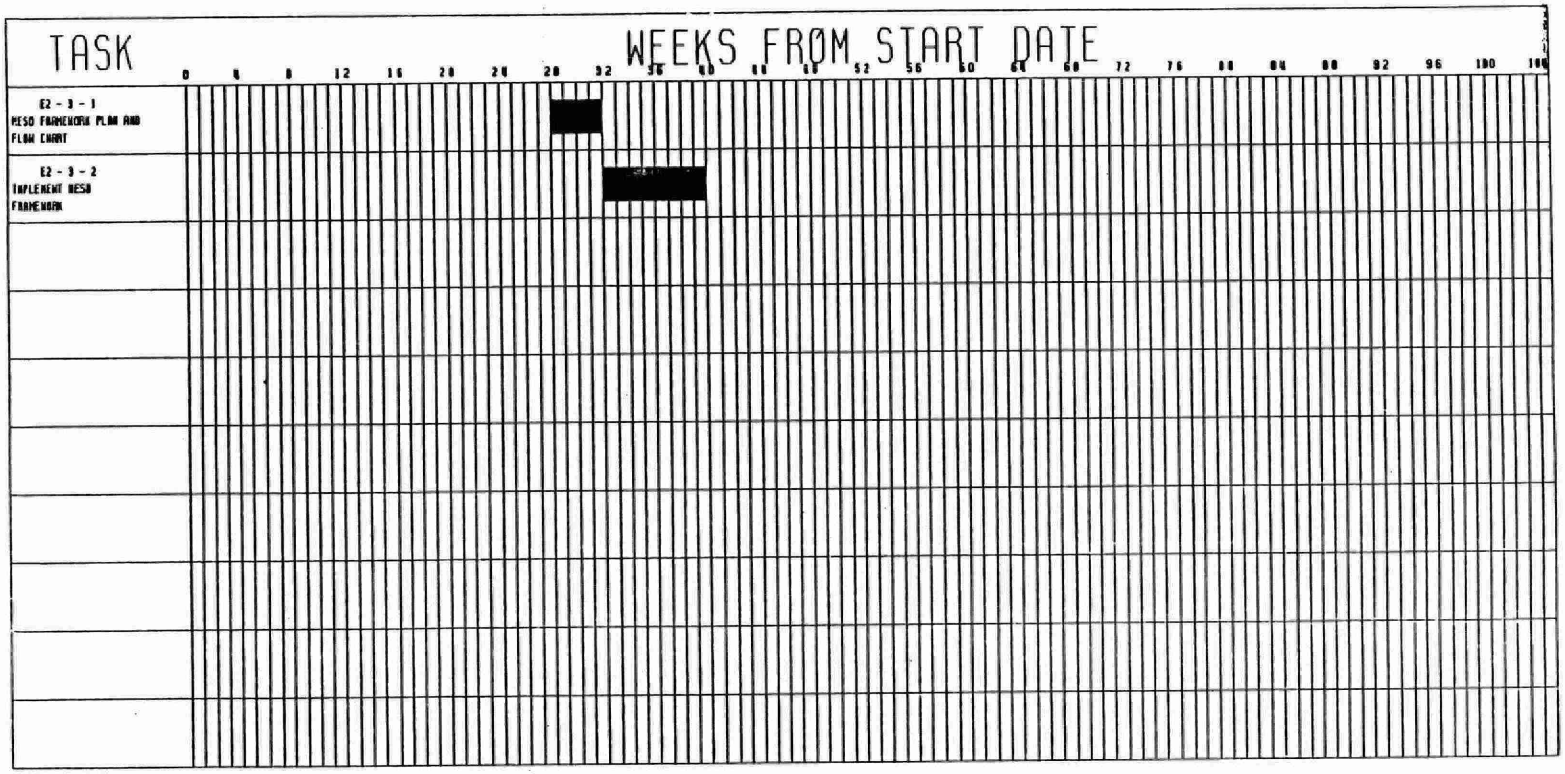
EI - 7 - 1
THEORETICAL FORMULATION REPORT
EI - 7 - 2
GUIDELINE FOR SUBMODULE USE IN FRAMEWORK REPORT


TASK
WEEKS FROM START DATE
E2 - 1 - 1
LAT FRAMEWORK PLAN AND FLOW CHART
E2 - 1 - 2
IMPLEMENT LAT FRAMEWORK


TASK
WEEKS FRØM START DATE
0
12
16
32
52
56
72
76
92
96
100
E2 - 3 - 1
MESO FRAMEWORK PLAN AND FLOW CHART
E2 - 3 - 2
IMPLEMENT MESO FRAMEWORK